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INVESTIGATIONS AND TEST OF WIRE ROPE CORE MATERIALS FOR AIRCRAFT ARRESTING ENGINE PURCHASE CABLE

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13. ABSTRACT

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5-21-71 NL

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An investigation and test of cores used in purchase cable for aircraft arrestment gear is made to determine if there is a core material superior to that presently used. Consultations with representatives of the wire rope industry and acknowledged authorities in the field of fibre testing, research and development are conducted. Wire rope core materials are selected and tested. Recommendations are made, with requirements for further testing, of possible superior substitutes.

I. INTRODUCTION

This study is concerned with the fiber core of the wire rope that is used in the purchase cables of aircraft arrestment gear. The natural fiber material, currently specified and used, exhibits a tendency to shred and this sign of deterioration necessitates early renewal of the cable.

A search for a better core material is pursued in contacts with the wire rope industry, which includes suppliers of cores and fibers. Consultations with acknowledged authorities in the field of fiber testing, research and development are conducted. Sample core materials are selected, manufactured and tested on the basis of theoretical causes of the problem of deterioration.

Test results and other available performance data are presented. Recommendations are made regarding the most promising materials to employ as substitutes for vegetable fiber core.

II. SUMMARY OF PROCEDURES AND RESULTS

A. Wire Rope Manufacturers. The problem of finding an improved core material is pursued with several of the leading suppliers of wire rope for purchase cables. Their favorable response to the purpose of this study and their contributions to a solution to the problem are brought out in the Text.

B. Core Manufacturers. Similar contacts are made with the major suppliers of core stock. It is axiomatic that the successful substitute core will be one developed by one of the manufacturers, with some technical aid or guidance from sources outside the industry. Here again, response is favorable and the results are detailed in the Text.

C. Contacts with Research Activities. The core problem is discussed with the head of research in a leading technical institute and with the technical marketing representative of the major supplier of synthetic yarns to the rope industry. Results are presented in the Text.

D. Visit to the Navy Rope Walk - Boston, Massachusetts. The head of this research activity of the Navy supplies expert guidance and advice as shown in the Text.

E. Selection of Test Samples of Core Materials. As a result of discussions with the core manufacturers, a meeting is arranged with the Technical Committee of the Cordage Institute The materials to be manufactured (and tested) are selected and the manufacturer of each is designated. Tests are discussed and recommendations are made to conduct specific tests as discussed in the Text. A commercial test agency with capabilities in the field of rope shapes is selected. The scope of the tests is discussed with the selected agency and suggestions are offered for their adaptation to meaningful tests.

F. Tests and Results. The materials which are tested and the tests which are conducted are as follows:

Materials	Tests
Sisal - base reference	Compressibility
Manila - base reference	Stretch and Recovery
Polyethylene	Dynamic Flexing
Polypropylene	Abrasion resistance
Nylon	Coefficient of Friction
Dacron	Softening Point

Requirements for the specific tests are developed with the United States Testing Company, Inc. and are described in detail in the text. On the basis of these tests the core materials are evaluated. Each test was scaled with a rating of 1 to 5. A rating of 5 was the highest rating and a rating of 1 was the lowest. The compressibility and dynamic flexing tests were multiplied by a factor of 2 since these were felt to be more important than the other tests. The sum of these ratings would indicate the material with the highest evaluation. Below are the results:

Dacron	34
Nylon	32
Polypropylene	27
Polyethylene	24
Sisal	23
Manila	23

III CONCLUSIONS

The results of the evaluation of the tests show that dacron, nylon and polypropylene, in that order, would be the materials best suited as wire rope core for the purchase cable.

These tests did not evaluate many of the factors which might influence the performance of the wire rope core. Some of these factors are:

1. The influence of tension, dynamic flexing and hard and soft laid rope on the transverse stiffness of the core.

2. The influence of tension, lubrication and hard and soft laid rope on the flexibility of the core.

3. The influence of lubrication and hard and soft laid rope on the resistance to abrasion and shear of the core.

4. The influence of length of time for recovery after release of load to abrasion and shear of the core.

In the light of the above, it is felt that no definite conclusions can be made as to the most suitable wire rope core material without additional testing.

IV RECOMMENDATIONS

It is recommended that purchase cable be made up with dacron core, nylon core and polypropylene core for full scale tests on an aircraft arresting engine. It is also recommended that additional testing be done on wire rope core materials to evaluate other influencing factors, enumerated above, on core performance.

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VIII REPORT TEXT

A. Background. The design or arrangement of wire rope, consisting of wires, strands and core, is called the construction. The classification of wire rope is the numerical designation of construction; it defines the number of strands placed around the core as well as the number of wires in each individual strand. The core of a wire rope supports the wire strands and maintains the position of strands during movement involving bending and load stresses.

There are many designs of wire rope construction to suit a large variety of applications. An arrangement of few wires of large size provides greater resistance to abrasion. One that is made up of more wires of small diameter gives more flexibility. The make-up of the core is such that the necessary degree of flexibility and longevity of the wire rope is satisfied. Thus the design is a compromise of component factors. The most successful design for a specific application is confirmed by experience with it in the field where the wire rope is subjected to extreme wear and destructive forces.

The wire rope that is used in the purchase cables of aircraft arrestment gear on board aircraft carriers must withstand high stress and endure what could be called maltreatment. The severe conditions are unalterable, however, so that if better wire rope performance is to be attained it will be accomplished through improvement in the quality of components. For study purposes we will concentrate on one size of purchase cable wire rope, namely:

a.	Diameter	1-3/8 inches
b.	Construction	6 x 19 (or 25 if the filler wires are included)
c.	Core	Manila and/or Sisal
d.	Specification	MIL-W-81178 (WEP), 9 February 1953
e.	Breaking Strength	175,000 lbs. minimum

As stated above, this wire rope is subjected to very high stresses. After repeated loading the natural fiber core tends to shred, manifested when bits of core material are expelled between the wire strands. This occurs early in what is considered to be the normal life of the wire rope, when the individual wires have not yet begun to fail.

After decades of successful performance, the natural fibers have, here, reached their limit of capability, in this one very strenuous application. Now the question is one of finding a satisfactory substitute. Is there a synthetic fiber now used commercially that will have greater resistance to shredding and perform well in all other respects? Is there a fiber yet untried that can be adapted to the purpose? What are the qualities and characteristics needed in a fiber that will be made into a core shape, i.e., those considered essential to successful performance? In comparison of various fibers after they are made into cores, what are the relative values of the qualities that can be properly measured and usefully assessed?

Report, reference (a), is the only available modern documentation on the subject of wire rope cores. The recommendations made in that Report regarding cores, which are pursued in this study, are:

1. The core will be designed for the maximum transverse stiffness consistent with strength requirements.

2. The core materials will be chosen for the least possible friction.

In general, information on cores of wire ropes has been developed and retained by private industry only. The wire rope manufacturers rely on the successful designs of cores, developed by the cordage manufacturers, when they order cores from them. This has also been the approach, until recently, by Defense Department activities where, for example, (see Specification, reference (b)) the core is described in very general terms, specifying the use of clean, uniform, hard fiber (manila and sisal) in commercial use. The high quality of the cores has met the needs and requirements of the wire rope manufacturers in the past and the subject has not been discussed in technical writings available to anyone outside the industry.

Quite recently new specifications for polypropylene rope and core have been issued. See references (c) and (d). Therefore, as far as information on cores is concerned, we start with almost a blank page. The word "almost" is used because there is a wealth of information available on ropes. In the use of this information we must keep in mind that although all cores are ropes, only specially designed and constituted ropes can be classed as proper cores.

A number of sources of information and technical data on ropes are listed in Section IX. Pertinent extracts from them will be used and identified throughout this report.

B. Wire Rope Manufacturers The manufacturers listed below have been approached to obtain information on new developments in the industry. They have been informed that a study of core materials has been initiated and mutual discussions were suggested. These companies, on the list of suppliers of purchase cables, are:

American Chain and Cable Company
American Steel and Wire Company
Bethlehem Steel Company
Broderick and Bascom Company
Donald Ropes and Wire, Ltd.
Jones and Laughlin Steel Corporation
MacWhyte Wire Rope Company

Visits to the MacWhyte, American Chain and Cable, and Bethlehem companies have provided a broad view as to what new core materials are in use and what additional ones are under consideration.

Polyvinyl has been tried as a core fiber but without complete success. Its pronounced resistance to chemical attack is not essential to purchase cables. In rod form its loss of flexibility at low temperatures and its tendency to stretch, when being closed into the wire strands, are factors that disqualify polyvinyl as a possible core. From another source in the chemical industry, it is learned that the molecules of polyvinyl do not properly orient themselves during the extrusion process so that the type of polyvinyl that otherwise could have useful qualities for core use fails to attain strength. Polyvinyl-covered sisal has been tried with some success but has been displaced by polypropylene. One company has tried the polyvinyl-covered fiber core with the fiber unlubricated and lubricated. In the first instance the fiber fails because of dryness and in the second case the lube breaks through the polyvinyl jacket and makes the core non-concentric. Both designs are pronounced unsuccessful.

Polyethylene core in the solid form does not elongate in the closing process (where the wire strands are formed around the core) but it has too much initial hardness and becomes harder with age.

One attempt has been made to impregnate fiber core with polyvinyl plastic, using no lubricant. This proves unsuccessful.

Nylon core is successful but is considered to be too costly, especially after the introduction of cheaper polypropylene. No adverse reports on nylon performance have been made however.

Glass fiber has been rejected by the wire rope manufacturers for the reason that it is prone to brittleness after repeated bending. Further consideration is given to it hereinafter.

There are no reports in the wire rope industry that Teflon core has been produced or tried.

Polypropylene is the synthetic fiber currently in most universal use as a core. It is considered to be the most successful substitute for vegetable fiber. The reported advantages are:

a. Filaments are uniform in size
b. Does not absorb moisture
c. Resists acids and oil
d. Has good resistance to abrasion
e. Has light weight
f. Can be extruded in filament form by the rope manufacturer from chemicals supplied in bulk by any of a number of sources
g. Only 3 to 6% by weight of lubricant is needed compared to 10 to 14% used in vegetable fiber cores.
h. Has greater strength than natural fiber

The one disadvantage, reported and considered to be minor by the wire rope manufacturers, is that the polypropylene must be used with caution where high heat is experienced. An example of one manufacturer's concern in this matter is his rejection of its use in large size wire rope for general use. The uncertainty of the nature of applications after the reel leaves the plant, especially as regards high heat exposure, is the reason for this action.

The high heat factor will be given further treatment in this study not only in relation to polypropylene but also as regards all synthetic fibers.

The several wire rope manufacturers whose plants have been visited apply most, if not all, of the following list of factors in their specifications for core manufacture:

a. Virgin material only.
b. Monofilament (relates to size)
   Fine - nominal 6 mils (.006")
   Coarse - nominal 12 mils (.012")
c. Multifilament - commercial
   Several 2 or 3 mils filaments are twisted together to make 6 to 12 mil filaments.
d. Use of stabilizers for heat and light.
e. Nominal diameter of core with a stated tolerance.
f. Required weight per foot
g. Required density
h. Amount of lubricant
i. Lay length
j. Specification, MIL-P 24116 (Ships), for certain Defense Department orders

There is no specification used, generally, for tensile strength or modulus of elasticity. The tightness of twist is a matter of good practice. One manufacturer states that no difference in wear resistance has been found between fine and coarse filaments. The same diameter of core is used for both natural fiber and for polypropylene.

One manufacturer uses multifilament polypropylene in elevator cables. Another will not use polypropylene at all in elevator cables because of a lack of experience with the material in all applications. This indicates some reservation in acceptance of the material for the time being.

The size of polypropylene core has been established in the industry at one-half the diameter of the wire rope in which it is used. This has been found to be a successful size to prevent the wire strands from locking into each other. It is a size that, coupled with the transverse compression strength of polypropylene, minimizes the tendency of the core to form a pronounced star shape when closed into the wire rope. This transverse strength derives not only from the fiber itself but also from the density and twist tightness of the core produced in its manufacture.

Typical set of catalogue literature from a major wire rope manufacturer is included in Section A of Design Data Report Number 1316, reference (e).

C. Core Manufacturers

The discussions with the core manufacturers focus attention on precisely what materials are available and what untried materials may prove to be successful. In Section B of Design Data Report Number 1316, reference (e), the information and the advice from one of the major companies reveal that there are a number of fibers that have already been used with satisfactory results. Because of its lower cost, polypropylene is the leader in commercial applications. The consensus of all rope manufacturers is that one or more of the synthetic fibers now used in ropes and in cores will prove to be satisfactory substitutes for the sisal cores now used in purchase cable wire ropes.

The following tables list the average values of breaking strength (pounds) and weight per 100 feet as contained in manufacturers' catalogues for a 5/8 inch diameter fiber rope. They show the synthetics to have greater strength and more satisfactory weight values than the vegetable fibers.

Rope - 5/8 inch diameter
Breaking - Strength - Pounds

1.	Sisal	3,520
2.	Manila	4,400
3.	Polypropylene	6,000
4.	Polyester (Dacron)	9,500
5.	Nylon	9,700
6.	Polyetheylene	5,200

Weight - Pounds Per 100 Feet

1.	Sisal	- 13.5
2.	Manila	- 13.5
3.	Polypropylene	- 7.5
4.	Polyester (Dacron)	- 13.0
5.	Nylon	- 10.3
6.	Polyethylene	- 8.1

The catalogue literature lists the following areas in which synthetic fibers perform well:

1. Durability
2. High shock absorbency
3. Resistance to moisture, rot, mildew, decay and fungus growth
4. Flexibility
5. * Ability to stretch and recover
6. Resistance to abrasion
7. Can be readily stabilized against normal heat and light effects

* Actually, manila has the best stretch and recovery characteristics in published literature.

In the characteristics listed below, the rope literature shows slight differences between the values assigned to the various synthetic fibers. As a result it is planned to obtain comparative data on the following in tests of sample cores:

1. Elongation and recovery, involving permanent stretch.
2. Abrasion resistance.
3. Coefficient of friction
4. Performance at high ambient temperature with high heat generated by working.

One important characteristic, resistance to transverse compression or squeezing, is not evaluated in catalogue literature. It bears a direct relationship to breaking strength but will nevertheless undergo further scrutiny in this study. This is a characteristic uniquely significant to core material because the core must support the wire strands.

Catalogue literature and a product chart supplied by one of the three major rope (and core) manufacturers is included in Section C of Design Data Report Number 1316, reference (e). It must be borne in mind that the information pertains to ropes, not cores specifically.

The core suppliers have recommended that the Technical Committee of the Cordage Institute be included in discussions of the problem herein. A meeting is arranged and the outcome is discussed in Section F below.

D. Contacts with Research Activities

Information obtained thus far indicates that successful synthetic fibers are available, that they can be made into rope shapes and that they possess qualities that make them appear superior to the standard natural fibers in many respects. The question then remains, how well will they function as cores for wire rope? How do they compare?

In an effort to narrow down the field of evaluation of characteristics, it appears advisable to consult knowledgeable sources engaged in research on synthetic fibers or ropes.

1. Naval Applied Sciences Laboratory, Brooklyn, New York

At the Applied Sciences Laboratory there is a continuing program of fatigue-testing 3/4" diameter wire ropes using various core materials, working them over various size sheaves. The amount of lubrication used in the test specimens is varied. Information is sought regarding the effect of coatings on corrosion resistance. All tests are run at moderate speeds with a tensile load of 6,000 pounds on the wires.

Two particular items of information obtained at this laboratory are of interest to this study:

a. In their assessment of wire rope longevity, they find that the lubricated wire ropes perform consistently better than the non-lubricated ones.

b. In regard to wire breaks and ultimate failure, the sisal-cored wire ropes have individual wire breaks distributed along the length of the sample. In the polypropylene-cored wire ropes, the breaks are concentrated at one point to the extent that the whole strand fails.

The unique failure of the polypropylene-cored rope raises several questions. Does this type of failure occur unusually early in the life of the rope, as compared to a sisal-cored rope fatigue limit, for instance? Is this peculiar to polypropylene or to synthetics as a whole? What characteristics of the fiber would cause this mode of failure? Can tests of the core materials, by themselves, reveal a possible cause and can the tests provide comparative data to indicate which fibers will last longer?

2. Research Department, Philadelphia Textile Institute

At the Philadelphia Textile Institute the following advice regarding cores in wire ropes is received:

a. The core and wire strands should work together without relative motion, having in mind permanent stretch.

b. It would be advisable to remove the greater inherent permanent stretch of the core before closing it into the wire strands.

c. Dacron has a stress-strain curve more nearly like that of steel wires than all other synthetic fibers used in ropes. The type of Dacron that is hot-stretched and restrained has a stress-strain curve more nearly like that of steel than ordinary Dacron.

d. It is expected that Dacron will possess, in a core shape, greater resistance to squeezing than other fibers.

3. Textile Fibers Department, DuPont Company, Wilmington, Delaware.

The visit to the DuPont Company and subsequent discussions with their technical representative has provided the following information and ideas regarding performance of synthetic fibers in core form:

a. Better performance may be obtained if the core acts uniformly and elastically with the wire strands.

b. The stretch and recovery characteristics would be improved by pre-stretching the core before closing into the strands.

c. One rope manufacturer has manufactured hot-stretch Dacron guys for high antennas to improve performance of the antennas with a non-conductor support. The hot-stretch Dacron appears to be the best material in regard to stretch; it is reported to have the least stretch and best recovery of all the rope synthetics. This could be an excellent recommendation for its use as a core in purchase cable.

Bulletins of technical information on synthetic fibers for ropes prepared by the DuPont Company are included in Section D of Design Data Report No. 1316, reference (e).

4. Textile Products Development Laboratory, Owens-Corning Corporation, Ashton, Rhode Island.

The Owens-Corning Corporation has a development program for uses of glass fibers. In reply to an inquiry regarding the possible use of glass fibers in a core, that company suggests the use of glass fibers embedded in rubber stock. In view of the lubrication of wire ropes, any rubber compound, even Buna-N or neoprene, would tend to swell. This factor may be disqualifying. Further probing of the use of glass fibers will continue.

5. A test program was recently completed at the Battelle Memorial Institute on the "Analytical and Experimental Investigation of Aircraft Arresting-Gear Purchase Cable," reference (g), which provides results of fatigue testing on 1-3/8 inch wire rope cycled over 24 inch sheaves at loads ranging from 20,000 to 110,000 pounds.

This investigation revealed that for the loads slightly over 90,000 pounds the mode of cable failure is due to fatigue failure of the outer wires at the points of interstrand notching. At the lower loads fatigue failure was initiated by the growth of multiple fatigue cracks in the wires on the crowns of the strands. At the higher loads the failure of the core to keep the strands separated permitted the wires of the adjacent strands to rub against one another resulting in cross-wire notching and eventual failure. To prevent this the core should be of a material with a high transverse stiffness.

E. <u>Visit to the Navy Ropewalk at Boston Naval Shipyard</u>

The Master Ropemaker and Technologist at this installation is the author of the only available modern textbook on ropes. Although, "The Technology of Cordage, Fibers and Rope", reference (f), is concerned chiefly with natural or vegetable fibers and not at all with cores, it offers much information that is applicable to core performance. In this restricted sense the contents of the book assist in preliminary comparisons and in selections of fibers and type of construction for the manufacture and tests of sample materials. Excerpts from reference (f), are included in Section E of Design Data Report No. 1316, reference (e).

The core does not share the tensile load in a stressed wire rope. The information from reference (f) presented below, therefore, does not stress data on tensile strength of ropes. The selected items are:

1. A harder and tighter twist is superior to a slacker twist for certain end uses. However, a tight twist serves to stiffer the rope and reduces its strength. A tight-twist or hard-laid rope has a higher percentage elongation than a soft laid rope for a given load. Thus, there must be a balance of factors to attain desired properties.

2. Components must be twisted in opposing directions to maintain compactness.

3. There are three basic mechanical stresses involved in the service of a rope:

a. Tensile pull (this is not important in a wire rope core).

b. Structural friction associated with bending and flexing.

c. Surface friction contributing to abrasion.

4. Secondary factors under dynamic conditions and repeated loadings are acceleration stresses and heat.

5. When a rope is bent there is movement of strand against strand, one strand rolling over another to produce compression in the inner part of the bend, and pulling away from each other to open out along the outer part of the bend.

6. A rope in a dynamic bending service will show considerable powdering and chafing on the surfaces where the strands are in contact with one another and, if excessively loaded, similar evidence of chafing internally.

7. In normal usage, ropes will be rubbed against themselves, against sharp edges both in straight tension and bending movements, be worked upon by internally and externally embedded grit, and thereby wear away. In most end uses, ropes are subject to external surface abrasion to such a degree that this constitutes the major cause for replacement due to service failure. (In the case of a core, the wire strands that envelop the core constitute the sharp edges noted above.)

8. In an analysis of factors involved in abrasion one must regard the point of abrasion as an area of extremely localized bending. If the rope is abraded by a metal edge, the compressive forces described as prevalent in tension or bending, are existent. If the surface wears away because of grit, each minute particle represents a condition of dynamic bending involving surface fibers which compress against the particle. Such deformations load the fibers in tension to the extent that they stretch and ultimately fail.

9. The ability to stretch is a property that is particularly associated with rope. Unlike rigid materials used in tension, ropes remain more or less permanently elongated after they are once stretched by an appreciable pull. Even after a long period of time has elapsed during which the ropes are no longer under load, they will remain partially stretched and show no complete recovery to their original lengths.

10. Unlike strength as a property, the elongation does not seem to be affected by the rate of application of the load. Studies show that the same ultimate elongation is attained whether the ropes are broken by extremely gradual loading or by sudden impact loading.

11. Ropes made of hard fibers do not stretch as much as some soft fiber ropes. A more extensible fiber will yield proportionately more elongation of the rope.

12. Once a rope is put in service and loaded, its elongation characteristics change. Having been stretched somewhat permanently by service load, it can be expected that in the loading range covered by service conditions, i.e., load generally up to 20 percent of the breaking strength, the constructional phase of the elongation curve will no longer be apparent. An additional effect of repeated loading as experienced in service, that should also be considered, is that

for every instance of load application, there will be some additional permanent stretch. The total stretch, per cycle, for a given degree of loading will diminish with frequency of service.

13. When the applied load resulting in stretch is released, the stretched rope will begin to contract in length. Unless the load is very slight - well below the normal working load range - the contraction, even over an extended period of time, is never complete. In a matter of minutes after the load release, half of the total recovery will be attained. (For the purposes of this study, early recovery is most important in view of the rapidity with which successive loads are applied.)

14. A rope that in comparison with its breaking strength is loaded in small degree will recover faster than when loaded in greater degree. When loaded in the range of their normal working loads, the smaller size rope will recover more readily. With respect to the effect of loads and rope sizes, nylon rope is not as much affected as the natural fiber ropes.

15. A four-strand rope shows less recovery than a three-strand rope; a hard-laid rope less than a soft-laid rope. Ropes that have been loaded repeatedly, thereby reaching a condition of maximum compactness under tensile load, will ultimately show complete recovery from stretch provided the applied load does not exceed the load used in pre-stretching the rope. (Cores are not normally pre-stretched. However, the load on the core is chiefly bending and squeezing rather than pulling or tensile.)

16. All the forces prevalent in the rope when it is pulled are prevalent when the rope is bent; in addition, there exists the factor of outer surface compression which in relation to the internal compressive for es, will tend to promote shearing stresses which further damage the rope.

17. Flexing (dynamic bending) endurance tests are regarded as only indicative of relative performance on one material against another, or one structure against another when both are tested concurrently under prevailing conditions. In conducting such tests, the ropes may be oscillated until they fail, or they may be oscillated for a prescribed number of cycles and evaluated on the basis of remaining strength. The first is a more desirable operation inasmuch as the rate of deterioration of rope due to internal abrasion seems to fit into a geometrical rather than an arithmetical pattern.

18. It is noteworthy that in any cordage flexing endurance tests, nylon is outstandingly superior in performance. (Since reference (f) was published, other synthetic fibers such as Dacron, polypropylene, etc., have been successfully introduced.)

19. Inasmuch as flexing endurance involves surface friction, improving the lubricity of the rope will improve its flexing endurance.

20. With increase in the degree of twist, there is a tendency to improve the flexing endurance.

21. Increasing the number of strands to lay the rope will generally have no pronounced effect upon the flexing endurance.

22. In cords and ropes of relatively small size, the effects of flexing and abrasion seem closely related; the cord that performs best in a flexing test generally shows a similar advantage in an abrasion test. This relationship will not be apparent in larger rope structures, particularly when the ropes are wet.

23. No matter how tightly three strands are twisted together, the rope will not be hard-laid unless there is enough twist in the strand to support and maintain the tight rope twist. The combination of rope and strand twist determines, in major degree, the overall hardness of lay.

F. Selection of Test Samples of Core Materials

The meeting of the Technical Committee of the Cordage Institute has served very well for the exchange of information and ideas. The membership includes representatives from companies that are suppliers and some that are not involved directly. This implies more objective treatment of the core problem in hand. The minutes of the meeting are included in Section F of Design Data Report No. 1316, reference (e). A comprehensive chart, "MAN-MADE-FIBERS" (Textile World), of interest to the conferees, is included in Section G of Design Data Report No. 1316, reference (e).

The deliberations of the Technical Committee are concerned with the following facts:

1. The core under study is standard sisal used in a wire rope 1-3/8 inch in diameter, lang-lay, with a tensile strength of 175,000 pounds. There are two 1000-foot long purchase cables in the arrestment gear, one on each side of the ship. The purchase cables connect the ends of the deck pendants to the arrestment engine.

2. An arrestment loads the cables for about three seconds; they can occur as rapidly as one each minute, several arrestments in succession. In each purchase cable, about 255 feet of pay-out takes place during an arrestment.

3. In a new cable the permanent stretch totals 1% or about eight feet. Thereafter, the elastic stretch and recovery amounts also to about 1%. The wire rope is not pre-stretched.

4. The sheaves over which the cables work are twenty-four or twenty-eight inches in diameter. Each cable passes around a complex of two sets of nine sheaves each at the arrestment engine. As a result, there is almost constant bending action of the cable as run-out occurs.

5. A purchase cable is expected to last for 1500 arrestments. Measurements have been made of wire rope diameter changes incident to failure. With a starting diameter of 1.42 inches and after a variable number of arrestments, the rope will fail when the diameter draws down to about 1.29 inches. Other measurements, not incident to failure, show the 1.42 inches diameter reducing safely to 1.38 inches. This indicates a narrow range between 3% safe reduction in diameter and a 9% reduction at failure.

Decisions were made at the Conference to manufacture and test the below listed core materials, with two samples being assigned to each of three leading core suppliers:

Sisal - base reference
Manila - base reference
Polypropylene
Polyethylene
Dacron
Nylon

The sisal, manila and polypropylene are to be lubricated according to standard practice; the nylon is to be pre-shrunk either in filament form or after the core is made.

Specifications are:

11/16 inch diameter
3 strand, single yarn
right lay
Z S Z construction
For use in Navy Aircraft Arrestment Gear Purchase Cable (1-3/8 inch diameter, 6 x 19 wire rope)
Delivery to Navy destination

The following information is to be supplied with each shipment:

Diameter of core
Lubrication - amount and code number
Lay - complete construction; rope, strand and yarn turns
Yarn size in denier or feet per pound
Number of yarns per strand
Weight per foot
Heat aging test
Type filament used, giving manufacturer of polymer or filament size, filament and manufacturer's code number

The following tests are discussed:

Compressibility
Elongation and recovery
Coefficient of friction
Abrasion resistance
Tensile strength of core
Fatigue or endurance test
Softening point

C. TEST PREPARATIONS

From the studies of commercially accepted, synthetic fiber core materials, it can be concluded that certain of their qualities are well-known and documented. Further, in the course of normal quality assurance, a measure of such characteristics as tensile strength, fiber size and make-up, light stabilization and the like will be properly established. Other areas must be explored, however.

It is necessary to obtain comparative test data in those critical areas that have not been pursued. These tests are selected after consideration of theories, described below, that suggest why the cores of purchase cable wire ropes fail. This approach is necessary because the core cannot be observed in operation nor can any measurements of stress and strain be readily obtained.

One theory on the cause of core failure pertains to the stresses, under load, suffered as the wire tope traverses the twenty-four inch diameter sheaves. Measurements and calculations indicate that the wire rope, during an arrestment, undergoes a 1% stretch; at the top of the sheave travel, the outer surface of the core by geometry stretches an additional 2%. There are other stresses also. At the top of the sheave travel, the outer strands of wire bear down on the core tending to squeeze it severely At the same time, the individual wires produce a shearing action that will sever the fibers and abrade them. The latter action is facilitated by the opening-out that takes place in the core strands along the outer diameter.

To resist the foregoing the core must have:

Transverse stiffness
Flexibility
Resistance to abrasion
Resistance to shear
Lubrication to promote sliding action and thus reduce abrasion.
Stability at the high temperatures experienced under high ambient conditions with heat generated by work.

The amount of transverse stiffness of the core or the ability of the core to support the strands without compressing to the point which will allow the strands to rub, is one of the most important qualities of the core.

The quality of the core to move relative to the wire strands with little friction and the ability of the core to flex on the strands without abrading is an important factor. When the core breaks down because of this abrasion, the wire in adjacent strands will rub and the rope will fail.

Taken by itself, stretching introduces a possible source of trouble. This results not from the stretching alone but from the degree of recovery. Further, the degree or amount of recovery relates to the recovery of the wire strands that envelope the core.

Neither the core nor the finished wire rope is pre-stretched in manufacture. Therefore, the constructional and the permanent stretch is removed in the use of the rope.

As has been noted above, the permanent and constructional stretch in a purchase cable has been measured at 1%. Thereafter, the wire rope by measurement stretches elastically 1% in each arrestment. However, the core may not conform to these percentages.

The chief difference between the wire rope and the core is the higher permanent stretch inherent in fibers. One rope manufacturer lists the following amounts:

Sisal	4.9%
Manila	4.8%
Polypropylene	3.8%
Polyethylene	5.8%
Dacron	6.2%
Nylon	8.0%

A factor that will increase the normal elongation of cores is their tight-twist construction. This yields more coils of strands per unit length than is the case with ordinary rope. As with a coil spring, the more coils, the more extension.

A further aggravation of the stretch problem in fibers is the slowness with which the elongation yields to recovery. The major manufacturer of synthetic yarns provides the following data in this regard:

Typical Extension and Recovery of "Broken-In" Ropes with Normal Working Loads. (Extension in % of Original Length)

	Nylon	Dacron	Manila, dry
1. Loaded to 20% of break	14%	5.5%	3%
2. Immediately after release from load.	3.5%	2%	1%
3 Five minutes after release from load.	1.5%	1%	1%
4. Two weeks after release from load.	0%	0%	0%

H. Tests The technical data for the core materials tested are listed in Table I.

Following is a description of the tests made to determine the relative qualities of the core materials selected:

1. Compressibility. This is a test to determire the amount of compression that occurs in the core material under increasing loads, and at various temperatures. The core in the purchase cable is compressed by the tension in the cable and the action of the strands on the core as the cable goes around the sheave.

The apparatus for this test is shown in Figure 1. The core was placed in a steel trough, the opening of which was equal to the diameter of the core. An anvil, the size of the trough opening was placed over the core. The assembly was placed in a Baldwin Universal Testing Machine and pressure was applied by the head of the machine to the anvil. The applied load was recorded and the motion of the head was determined with use of an indication dial. To obtain the compressibility data for the elevated temperatures, heat lamps were directed on the test assembly until the desired temperature was obtained.

To get comparative data the zero deflection must be the same for all the core samples. A load of 100 pounds was applied to the sample. The compression at this load was established as the zero deflection for each sample.

The test procedure was as follows:

(a) A 1000 pound load was applied to the sample and held for three seconds. The deflection was measured and the load released.

(b) At end of one minute the load was increased to 2000 pounds, held for three seconds and the deflection measured again.

(c) The above was repeated in 1000 pound load increments until the core was compressed to three-fourths of its original diameter, a deflection of 0.172 inches.

(d) The above test was repeated at temperature of 120°F. and 180°F. The samples tested at the elevated temperatures were heated to the temperature of the test for ten minutes before starting the test.

Two tests were made at room temperature, one at 120°F. and two at 180°F.

2. Stretch and Recovery. This is a test to determine the amount of stretch and the amount of recovery that occurs when the core is loaded and released. The core in the wire rope should stretch and recover the same amount as the wire strands when the wire rope is loaded and released.

The apparatus for this test is shown in Figure 2. Six foot test samples of each material were made up with eye splices on the ends. The sample was attached to head and base of the Baldwin Universal Testing Machine as shown in Figure 2. Three samples of each core material were tested as follows:

(a) A tensile load of 100 pounds at a head speed of 4 inches per minute was applied to the core. With this load held, a gage length of 30 inches was marked on the core.

(b) An increasing tensile load was applied to the core until the 30 inch gage length was stretched to 30-1/2 inches. The load was recorded and held for three seconds.

(c) The load was reduced to 100 lbs. and the original 30 inch increment was remeasured noting the reduction in length or recovery.

(d) At the end of one minute the tensile load was increased until the 30 inch length was stretched to 31 inches. The load was recorded and held for three seconds.

(e) The load was again reduced to 100 lbs., the 30 inch length was remeasured and the recovery was recorded.

(f) The above was repeated at intervals of one minute in increments of 1/2 inch until a maximum of six inches of stretch was recorded or until the core failed.

(g) The above test was made for three samples of each core.

(h) Two samples of each core material were pre-stressed to forty percent of their ultimate strength and steps "a" through "f" were repeated.

3. Dynamic Flexing. This is a test to determine the effect of flexing the cores over a sheave. The sheaves used for this test had diagonal ribs welded on the rope contact surface to simulate the squeezing and wear caused by the wire strands on the core as the

wire rope runs over the sheaves.

The apparatus for this test is shown in Figure 3. The chain from an overhead hoist was attached to an eye splice in one core specimen. This core specimen and another were wrapped around a three inch and a twelve inch sheave as shown. With this arrangement two samples can be tested at one time. Attached to the twelve inch sheave were two cams which actuated a switch reversing the hoist motor As the rope cycled, the sheaves rotated so that there was no relative motion between the sheave and the rope. This test set up was capable of cycling the rope at 5 cycles per minute.

(a) A sample of each core material was tested on the three inch sheave and the twelve inch sheave.

(b) The cores were oscillated over the sheaves by the reversing of the hoist motor.

(c) The test was continued until the core failed, at which time the number of oscillations was recorded.

(d) The above test was repeated for five samples of each core on the three inch sheave and one sample of each core on the twelve inch sheave.

4. Abrasion Resistance. This is a test to compare the abrasive qualities of the core materials.

The apparatus for this test is shown in Figure 4.

(a) The core specimen was attached to the drum, layed over a fixed hexagonal bar, and a 5.2 pound weight was attached to its end.

(b) The drum oscillated, causing the core to abrade against the hexagonal bar as shown in Figure 4. The drum oscillated at the rate of 3C) cycles per -min. Four samples can be tested at one time with this test setup.

(c) When one strand of the core wore through, the test was stopped and the number of cycles was recorded.

(d) One sample of each core was immersed in water for forty-eight hours and the test was repeated for the water-soaked cores.

5. Coefficient of Friction. This is a test to determine the coefficient of friction of the core materials.

The test setup is as shown in Figure 5 and the test procedure was as follows:

(a) The core was placed on the flat stainless steel plate, and a 50 pound load was placed on the core, guided on both sides so that it would not tip. The rope was pulled by a calibrated spring scale.

(b) The force required to start the rope in motion was recorded.

(c) The force required to continue the rope in motion was recorded.

(d) The above test was repeated for one sample of each core.

6. Softening Point. This is a test to get comparative information on the effect of heat in softening the core materials.

The apparatus for this test is as shown in Figure 6. This test is the standard method for testing for "Deformation of Plastics Under Load ASTM-D621."

(a) The core specimen was placed in the test machine and a load of 200 pounds per linear inch was applied without shock.

(b) The initial deformation was recorded and established as the zero point.

(c) The testing machine was placed in a test chamber which was heated to a temperature of 180°F.

(d) The deformation was recorded after 1/2 hour and 1 hour time increments.

(e) The above test was repeated for one sample of each core.

J. Results. The data collected in the performance of each of the above tests is tabulated in Appendix A.

The results of the above tests are shown in Figures 7 thru 17. The curves shown in these figures were made up of the average values of the data obtained.

1. Compressibility. Figures 7, 8 and 9 show the comparison of the compressibility or transverse stiffness of the core materials. Sisal and manila had the greatest transverse stiffness of the materials tested at all three test temperatures. In all cases the compressibility increased with increasing temperature. At 4000 pounds load the increase in compressibility for a temperature increase of 70°F to 180°F is as follows:

Sisal	Manila	Polypropylene	Polyethylene	Dacron	Nylon
48%	14%	14%	9%	5%	11%

An attempt is made from the data received to compute the bulk modulus of elasticity of the core materials. The procedure used for this calculation is shown in appendix A. Because the test specimen was not completely enclosed during the compression test, (see Figure 1), the deflection data could not be taken as compression of the material and therefore the results are not considered to be an exact indication of the bulk modulus. They do, of course, indicate comparative values of the bulk modulus. The manila and sisal had the greatest bulk modulus. The nylon, dacron, polyethylene and polypropylene all had about the same value for the bulk modulus. The core samples used for this test were as received from the manufacturer. No tests were made of the rope cores after they had been flexed or stretched.

2. Stretch and Recovery. Figures 10 and 11 show the relationship of elongation versus load of the core materials. In general the effect of elongation in itself is not an important factor in wire rope core. These curves are a by-product of the testing to determine the recoverability of the core materials. The curves shown for the elongation of the manila and nylon compare favorably with curves shown in reference (f.). The sisal and manila rope for both the "as received" and prestressed rope elongate the least. The dacron and nylon elongate the greatest amount. As would be expected the elongation is less in the pre-stressed rope than the "as received" rope, since the rope stretches at a greater rate in the first 20 percent of load application. This is consistent with test results shown in reference (f).

Figures 12 and 13 show the comparison of the recoverability of the ropes. The purchase cable of the arresting engine stretches and recovers 1% of its length during an arrestment. The ideal rope core would duplicate this. Figure 12, showing the "as received" rope, indicates that all the ropes except the sisal recover about 0.5 percent for a 1% elongation. The sisal recovers about 0.3 percent. The results could not be compared with data from reference (f) since the data shows an immediate recovery. Reference (f) gives percent recovery after 15 minutes and longer.

Figure 13, showing the pre-stressed rope indicates that all the ropes recover 1 percent for a 1 percent elongation.

At the end of the stretch and recovery testing all ropes were tested to failure. Below are the results:

Rope - 11/16 Inch Diameter

Breaking Strength (Average) Pounds

		As Received	Pre-Stressed
1.	Sisal	3,766	3,915
2.	Manila	5,090	5,055
3.	Polypropylene	7,907	7,780
4.	Polyethylene	4,240	4,570
5.	Nylon	9,453	9,580
6.	Dacron	9,653	9,055

3. Dynamic Flexing. Figures 14 and 15 show the comparison of the ropes subjected to flexing over a 3 inch and a 12 inch sheave. The sheaves had diagonal ribs welded to the rope contact surface to simulate the effect of the wire strand on the core. The 12 inch sheave more nearly duplicates the condition of the wire rope core in the purchase cable traversing the 24 inch sheave. The 3 inch sheave was used to accelerate the testing of the rope. In both cases, the nylon core faired the best. It wore two times as long as the dacron. The dacron was far superior to the others, with polypropylene being the next best.

These results agree with data supplied by the leading cordage manufacturers. Information given in reference (f) also notes that for flexing endurance nylon cordage is superior in performance.

It was noted upon inspection of the test samples of the failure that there were some indications of rubbing between the sheave and the rope, so that abrasion possibly added to the dynamic flexing to produce the failure.

4. Abrasion Resistance. During an arrestment, as the purchase cable bends around the sheaves, the strands of the core will rub against one another and the wire strands. Figures 16 and 17 show the comparative abrasive resistant qualities of the core materials. Here again the nylon and the dacron outlasted the other rope. The test of the dry core materials showed that the nylon and dacron lasted for 350,000 cycles with only a slight indication of wear; the polypropylene showed heavy wear at 350,000 cycles, the polyethylene failed at 62,000 cycles, the manila at 113,000 cycles and the sisal at 39,000 cycles.

5. Coefficient of Friction. Table II shows the comparative values of the static and dynamic coefficient of friction for the core materials. The polyethylene proved to have the lowest coefficient of static and dynamic friction, 0.15 and 0.14 respectively, while manila had the greatest - 0.27 and 0.26 respectively. The values for dacron and polypropylene were also low.

6. Softening Point. Table III shows the effect of temperature on softening of the core materials. The nylon was affected the least by the increased temperature, deforming 0.58 percent after 1/2 hour and 0.73 percent after 1 hour. The polyethylene and polypropylene deformed the greatest amount, deforming 1.9 and 1.75 respectively after 1/2 hour and 3.05 and 2.04 percent after 1 hour.

This test is related to the "resistance to squeezing" test described in paragraph J-1 above, except that in one case the core is enclosed and in the other it is not. Figure 9 does show agreement in that manila and sisal does deflect the greatest amount and nylon and dacron the least at the elevated temperatures.

In order to determine which of the cores performed the best for all the tests described above, a rating of 1 thru 5 is given to each for each one of the tests. An additional factor of 2 is multiplied by the rating for the transverse stiffness and flexibility tests since these are felt to be the most important. The core with the highest total from this rating would have the best performance. The following are the results:

Core	*Transverse Stiffness	*Flexibility	Abrasion	Friction	Recoverability	Temp.	Total
Sisal	10	2	1	3	4	3	23
Manila	10	2	2	1	5	3	23
Polypropylene	6	6	3	5	5	2	27
Polyethylene	6	4	2	5	5	2	24
Nylon	4	10	5	3	5	5	32
Dacron	6	8	5	5	5	5	34

*Rating times 2.

K. Conclusions. As stated throughout the text of this report, the ideal wire rope core would be one that had the following:

1. Transverse stiffness to support the wire strands under conditions of high loading around sheaves to prevent rubbing of the strands against each other.

2. Flexibility to allow the dynamic bending around the sheave without failure of the core fiber or strands.

3. Resistance to abrasion and shear to prevent failure of the core as it rubs against the wire strands.

4. Recoverability to allow the core to stretch and recover with the wire strands and thereby reduce to a minimum relative motion between the wire strand and the core.

5. Stability at high temperatures which would be experienced by the core due to high ambient condition and heat generated by the work.

The rating table, shown in paragraph J of this section, which considers the above factors, concludes that the dacron core would give the best performance as a wire rope core.

These tests did not evaluate many of the parameters affecting the above factors which contribute to the determination of the most suitable wire rope core. Some of the parameters which should be considered are:

a. Transverse stiffness of the rope with increasing tension loads.

b. Transverse stiffness of the rope after it had been dynamically flexed at an increasing number of cycles.

c. Transverse stiffness of the core for hard and soft laid rope.

d. Flexibility of the core with increasing tension loads.

e. Flexibility of hard and soft laid rope.

f. Flexibility of lubricated and non-lubricated rope.

g. Resistance to abrasion and shear for lubricated and non-lubricated rope.

h. Resistance to abrasion and shear for hard and soft laid rope.

i. Instantaneous recovery of the rope after release of load.

In the light of the above, it is felt that no definite conclusion can be made as to the most suitable wire rope core material for an arresting engine purchase cable without additional testing.

L. Recommendations. It is recommended that purchase cable be made up with dacron core, nylon core and polypropylene core for full scale tests on an aircraft arresting engine. It is also recommended that additional testing be done on the wire rope core material to determine the following:

1. The effects of rope tension, dynamic flexing and hard and soft laid rope on transverse stiffness.

2. The effects of rope tension, hard and soft laid rope and lubrication on flexibility.

3. The effects of hard and soft laid rope and lubrication on resistance to abrasion and shear.

4. The instantaneous recoverability of the rope after release of load.

IX REFERENCES

a. NAEL-ENG-7014 (14 February 1964) Study of Designs for an Optimum Wire Rope for Aircraft Arresting Systems.

b. Specification MIL-W-6015A (ASG) 9 February 1953. Wire Rope, Steel, 6 x 19, High Strength (for Aircraft Launching and Arresting).

c. Specification MIL-P-24216 (SHIPS) 25 March 1966. Polypropylene Cores for Wire Rope.

d. Specification MIL-R-24049A (SHIPS) of 28 March 1966. Rope, Polypropylene

e. Design Data Report No. 1316

f. "The Technology of Cordage, Fibers and Rope" by David Himmelfarb.

g. "Analytical and Experimental Investigation of Aircraft Arresting-Gear Purchase Cable" by P.T. Gibson, R.H. Fress, R.O. Winegardner, D.E. Retlit, D.W. Hoeppner, W.S. Hyler and H.A. Cress.

TEST APPARATUS
COMPRESSIBILITY

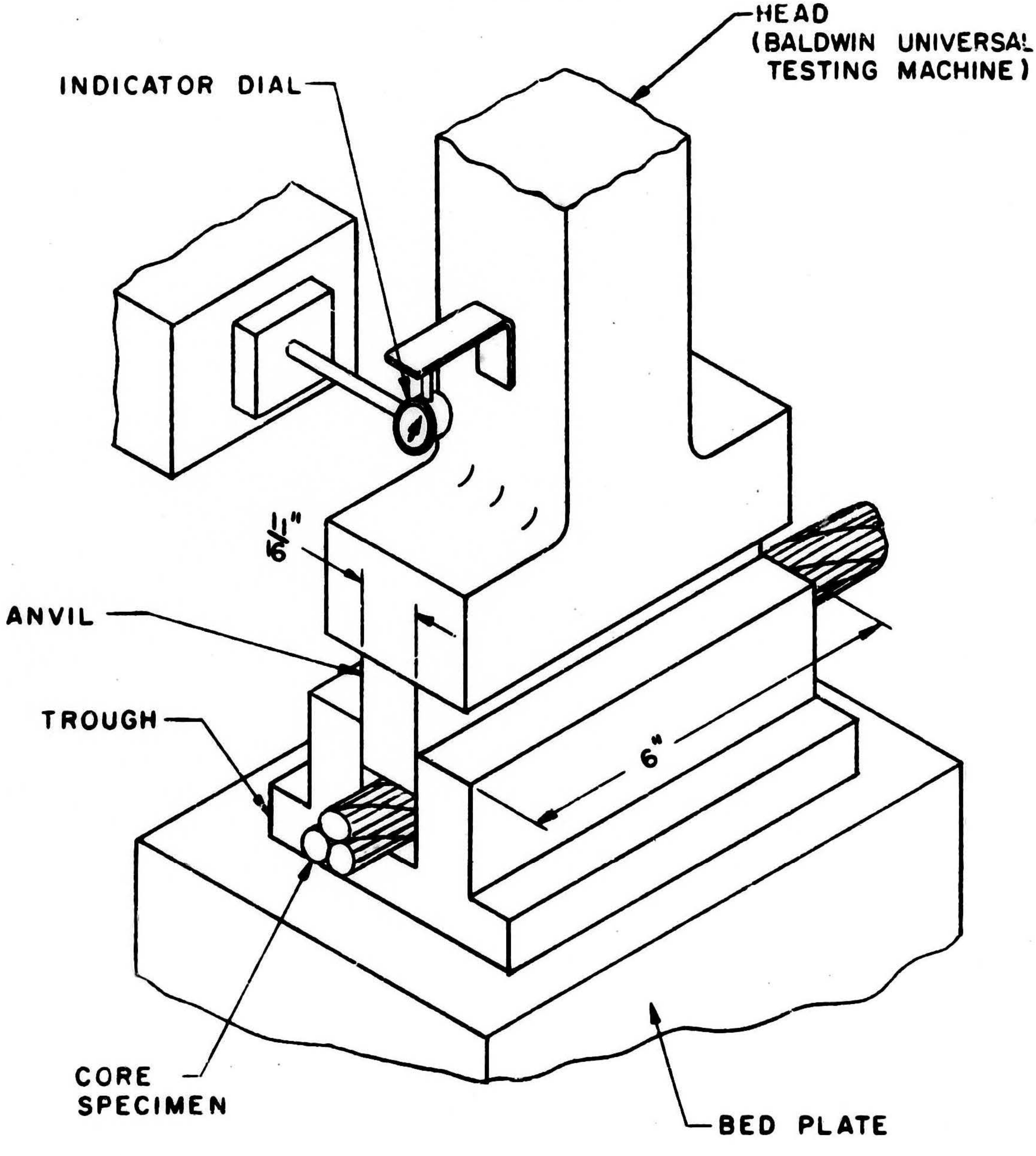


FIGURE NO.1

TEST APPARATUS
STRETCH & RECOVERY

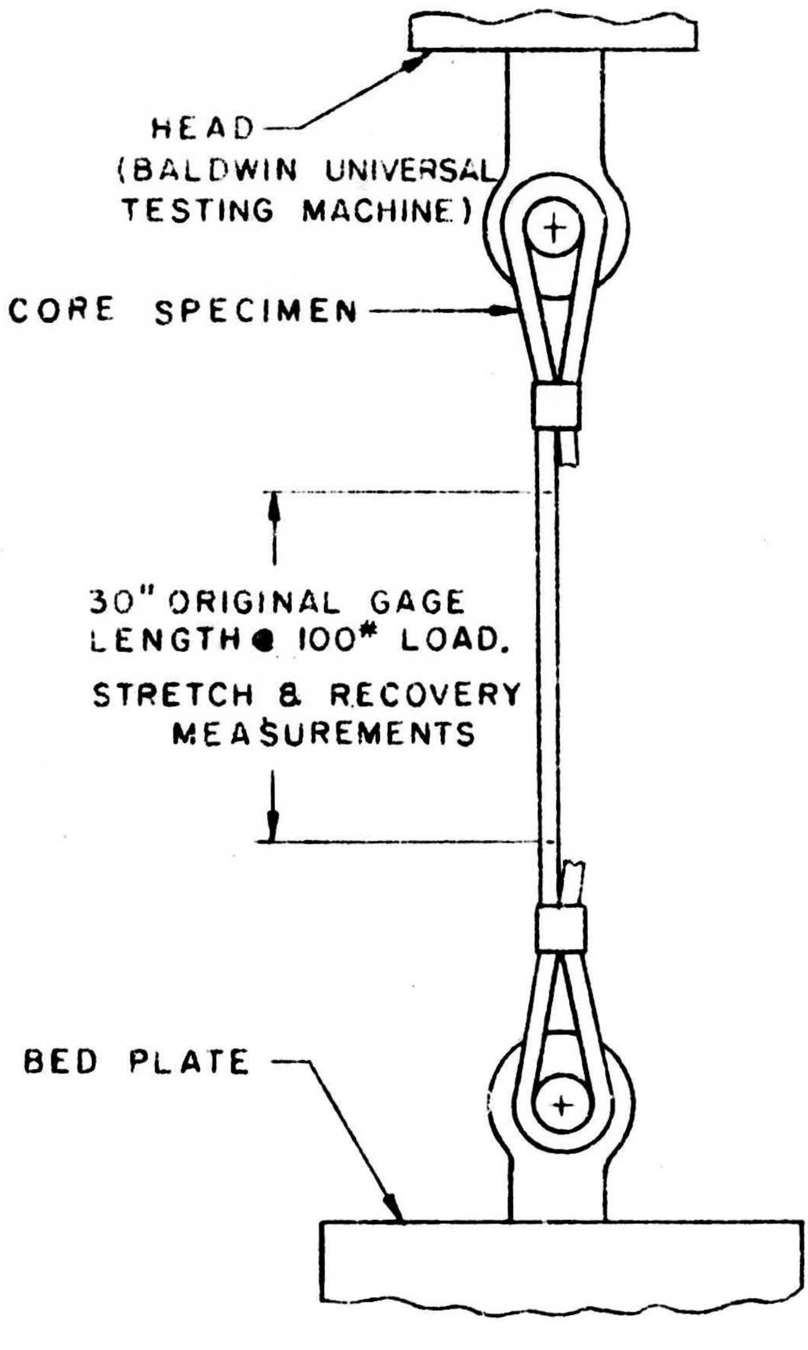


FIGURE NO. 2

TEST APPARATUS
DYNAMIC FLEXING

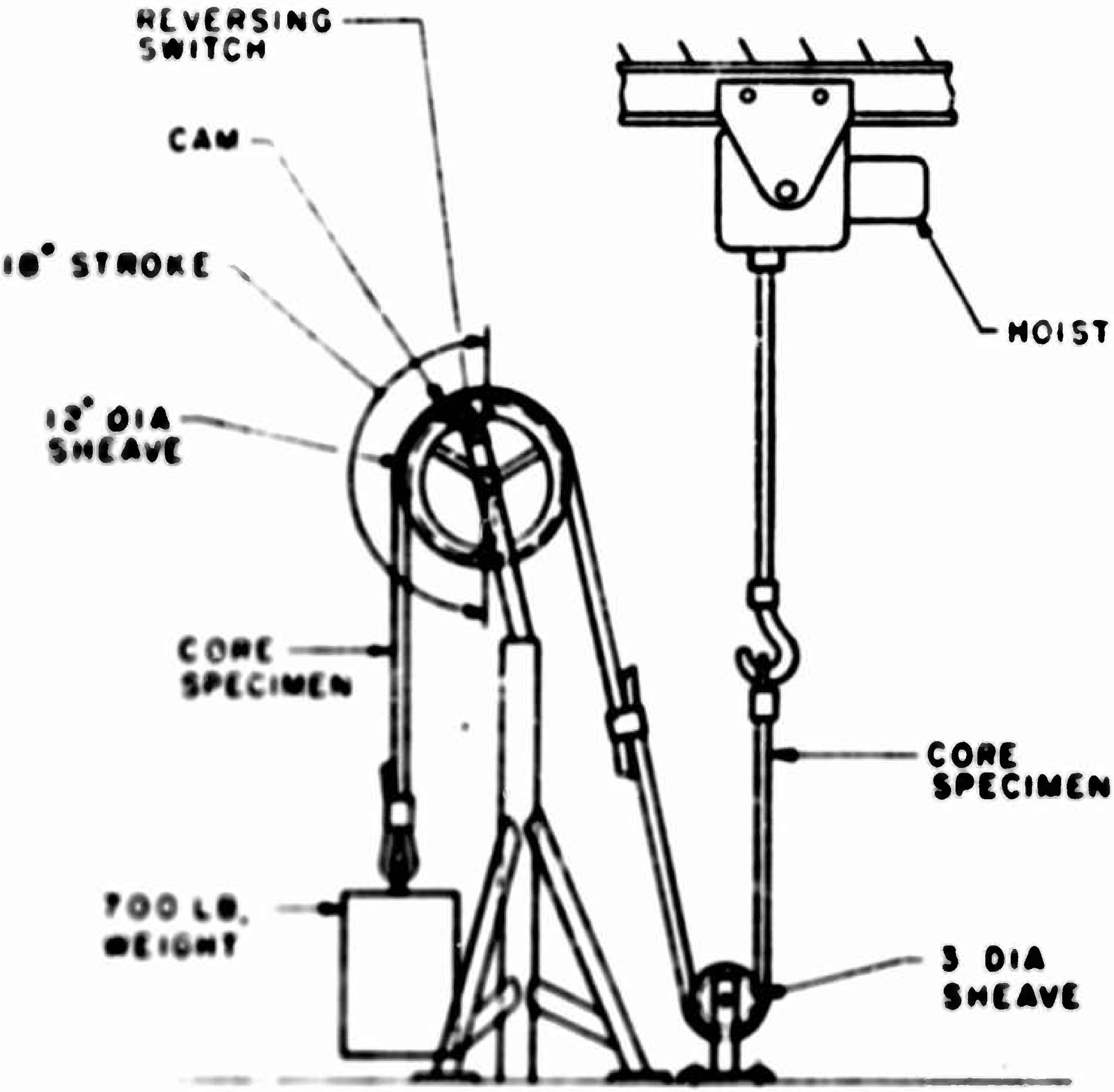


FIGURE NO. 3

TEST APPARATUS
ABRASION RESISTANCE

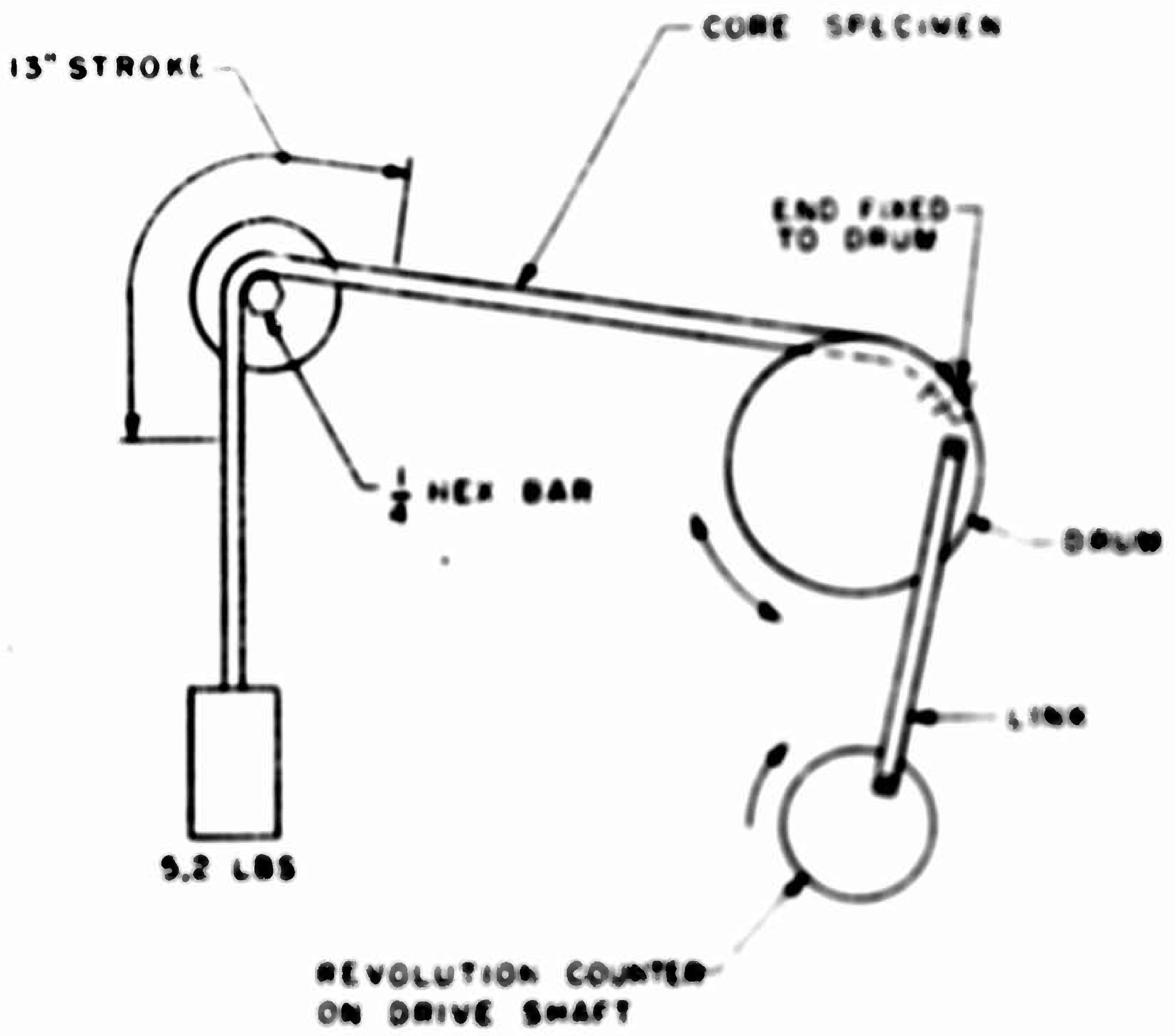


FIGURE NO. 4

TEST APPARATUS
COEFFICIENT OF FRICTION

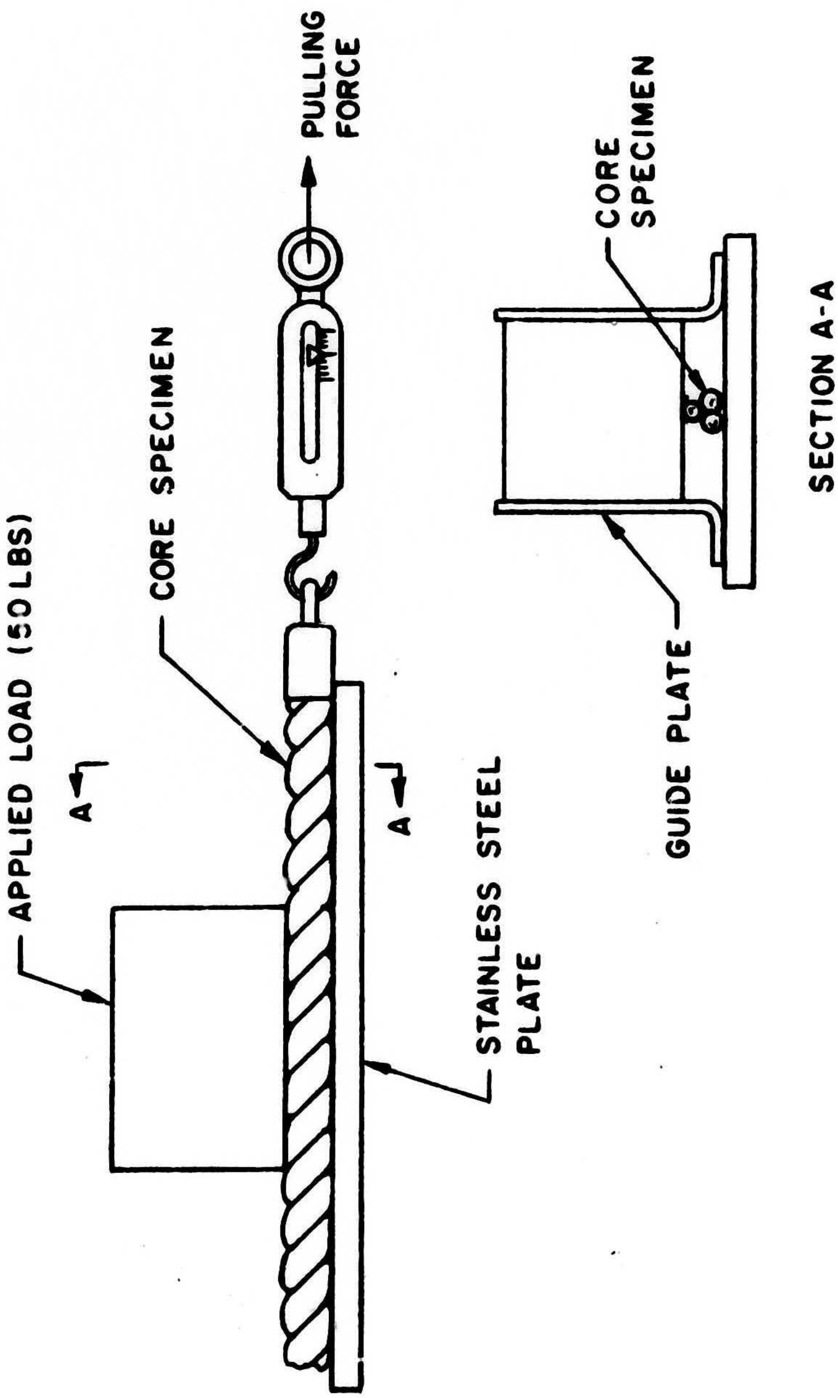


FIGURE NO. 5

TEST APPARATUS
EFFECT OF HEAT ON DEFORMATION

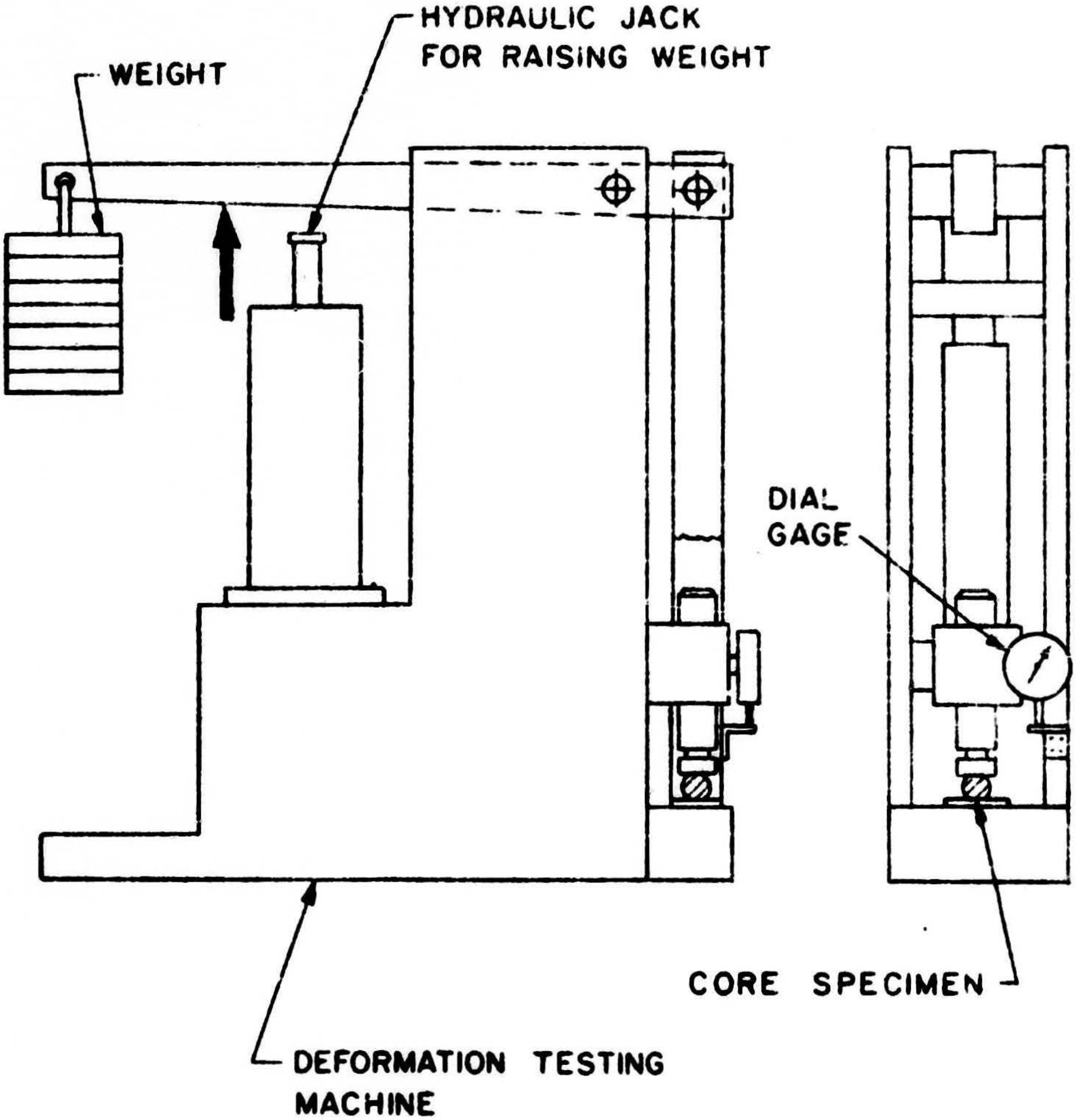


FIGURE NO. 6

RESISTANCE TO SQUEEZING

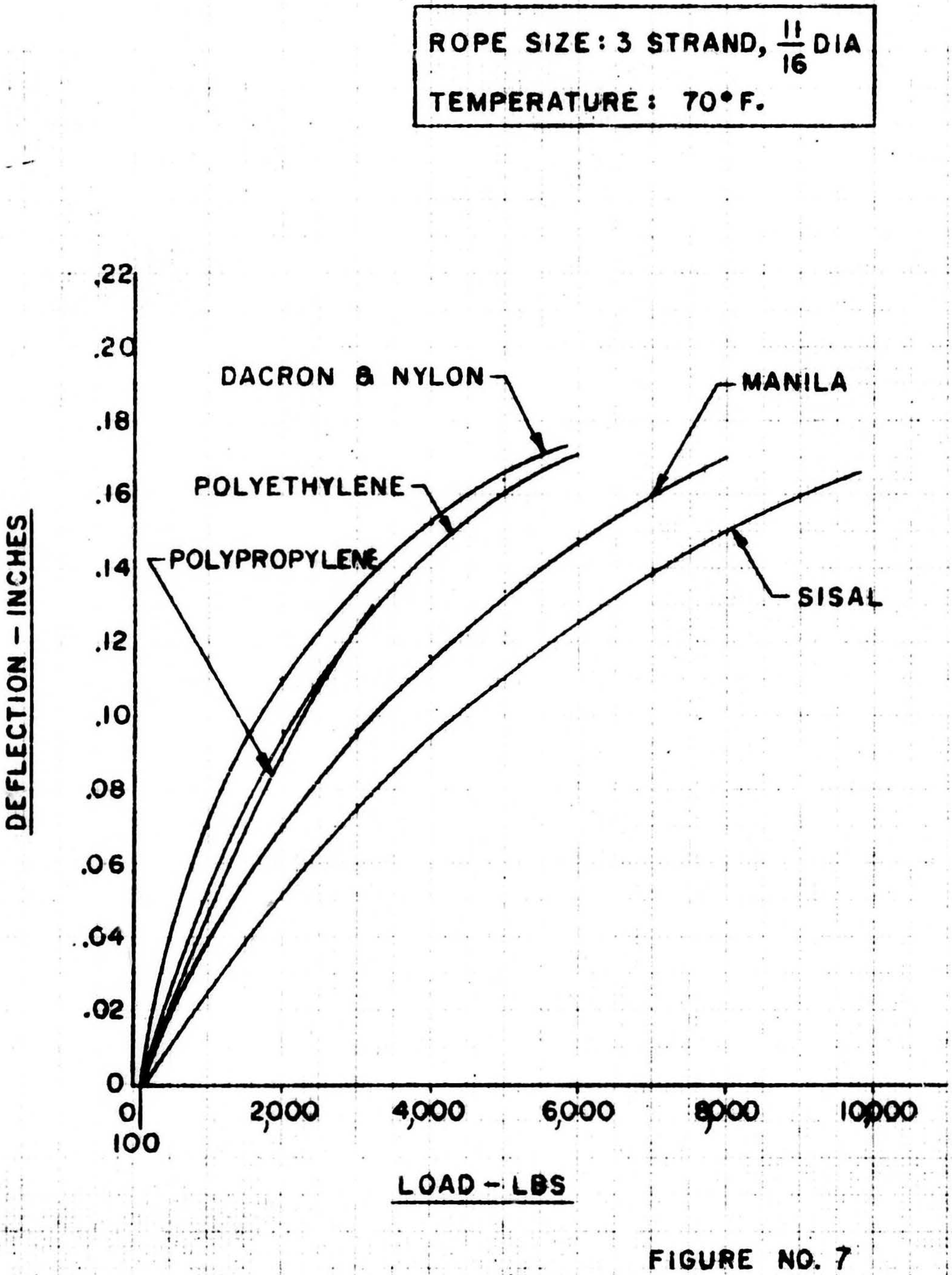


FIGURE NO. 7

RESISTANCE TO SQUEEZING

ROPE SIZE: 3 STRAND, $\frac{11}{16}$ DIA

TEMPERATURE: 120° F.

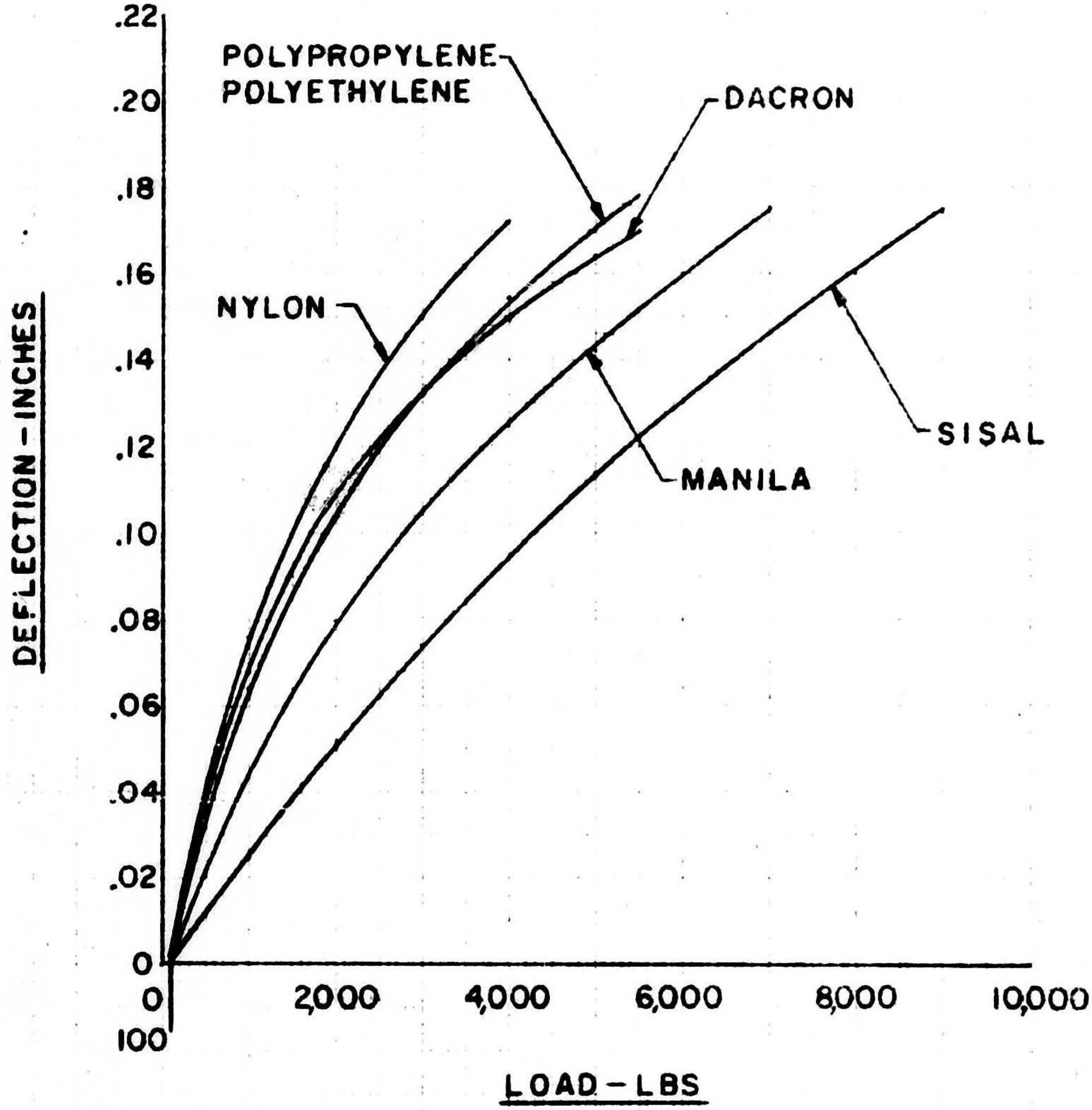


FIGURE NO. 8

RESISTANCE TO SQUEEZING

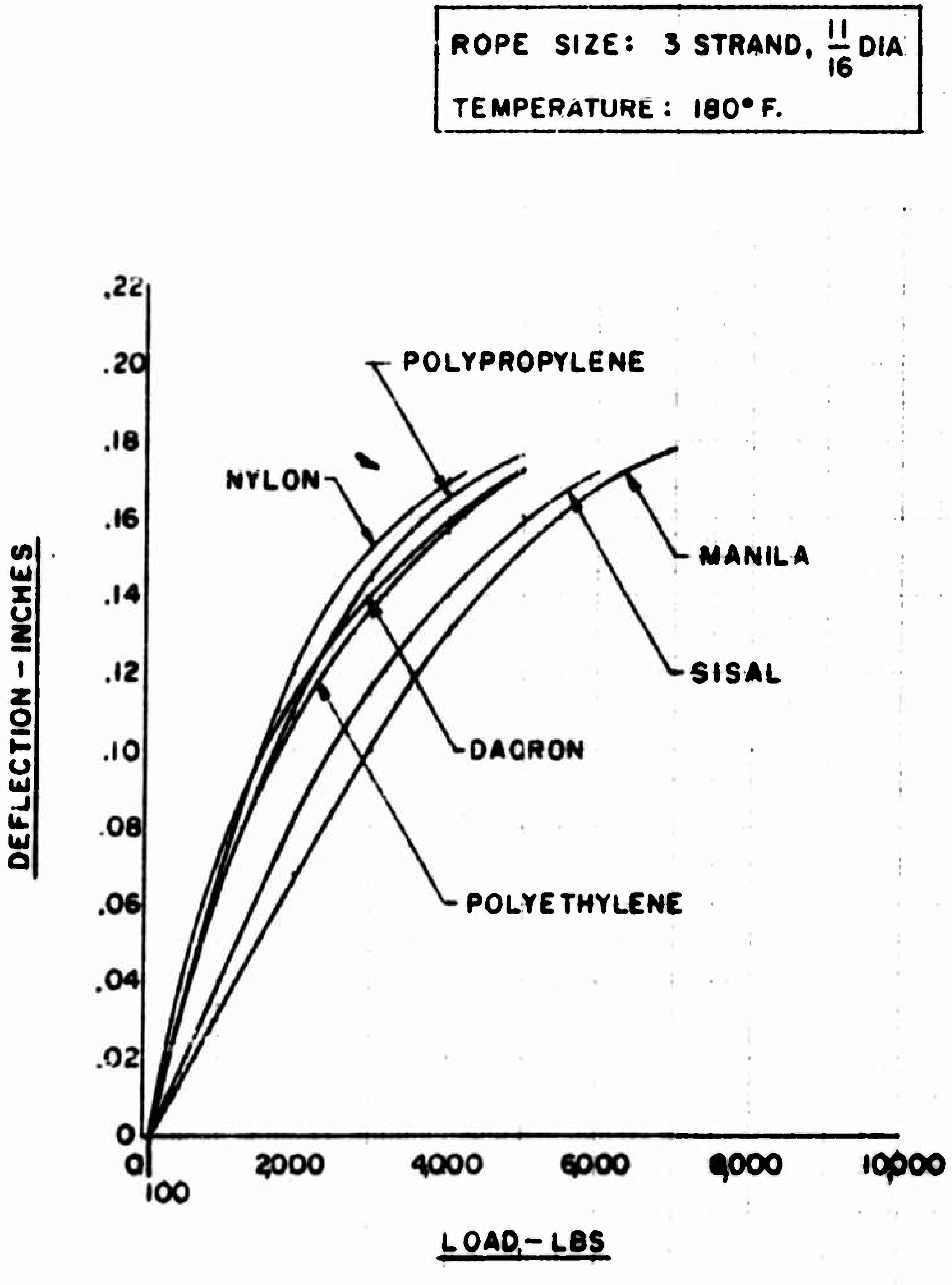


FIGURE NO. 9

ELONGATION VS LOAD

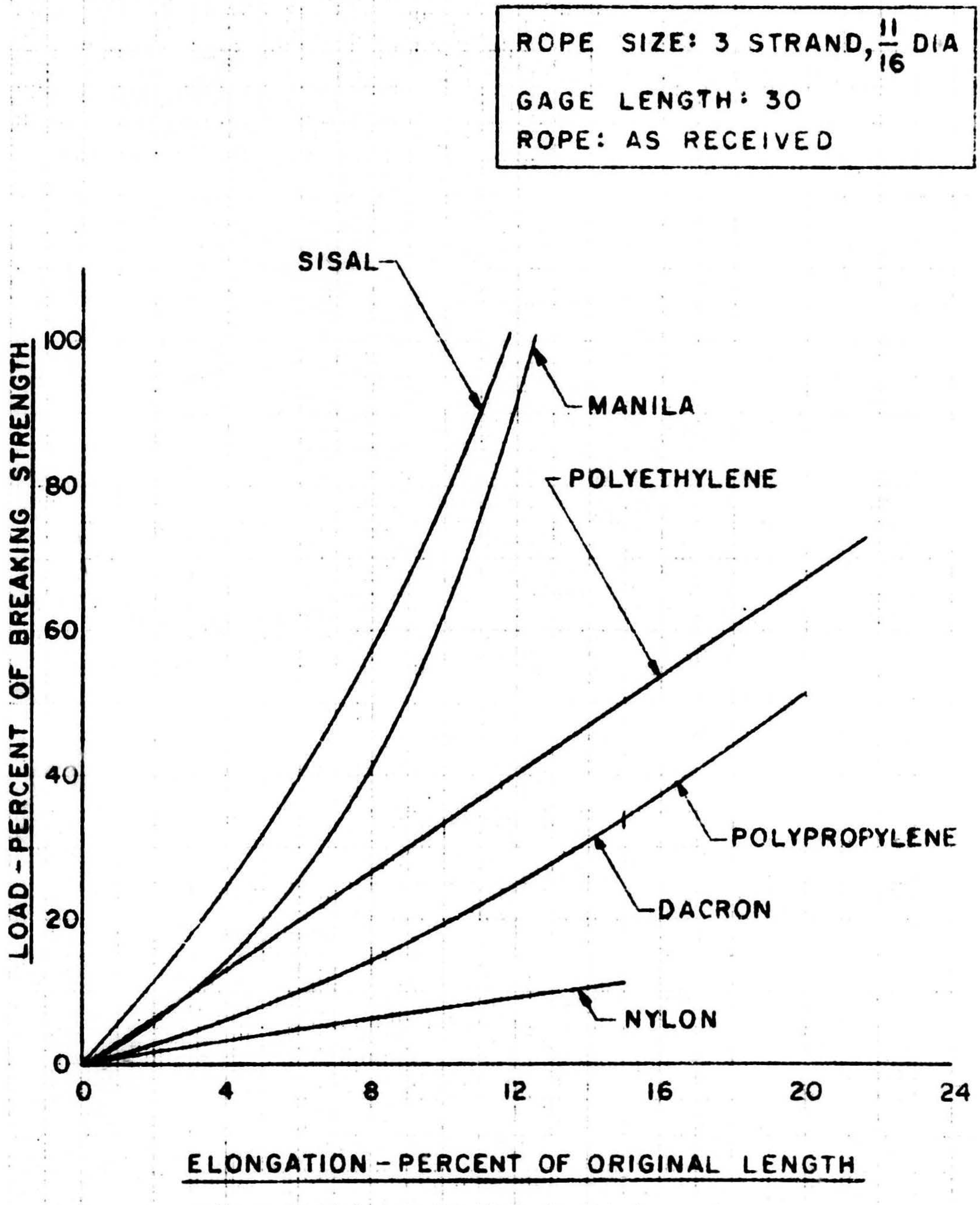


FIGURE NO. 10

ELONGATION VS LOAD

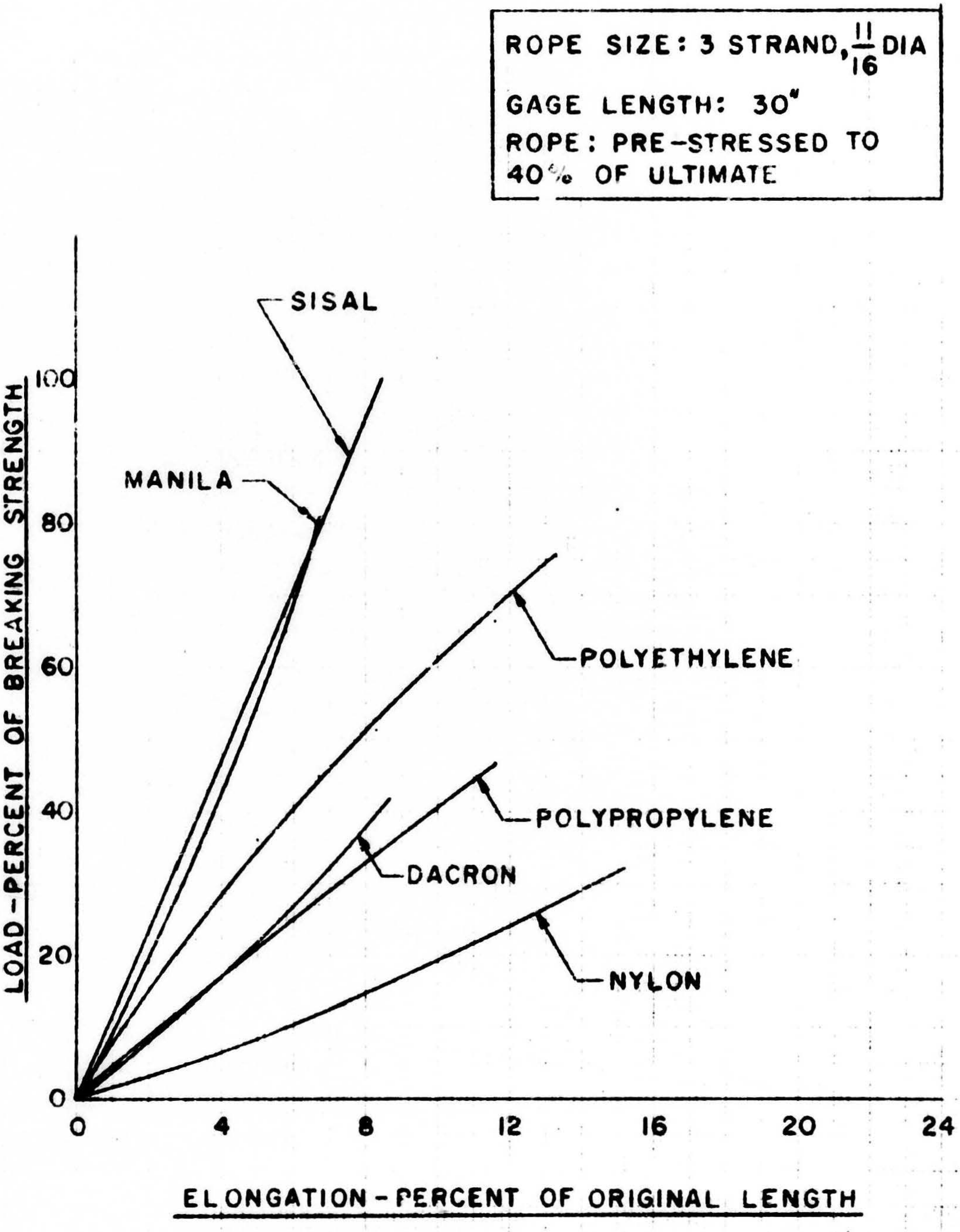


FIGURE NO. 11

RECOVERY VS ELONGATION

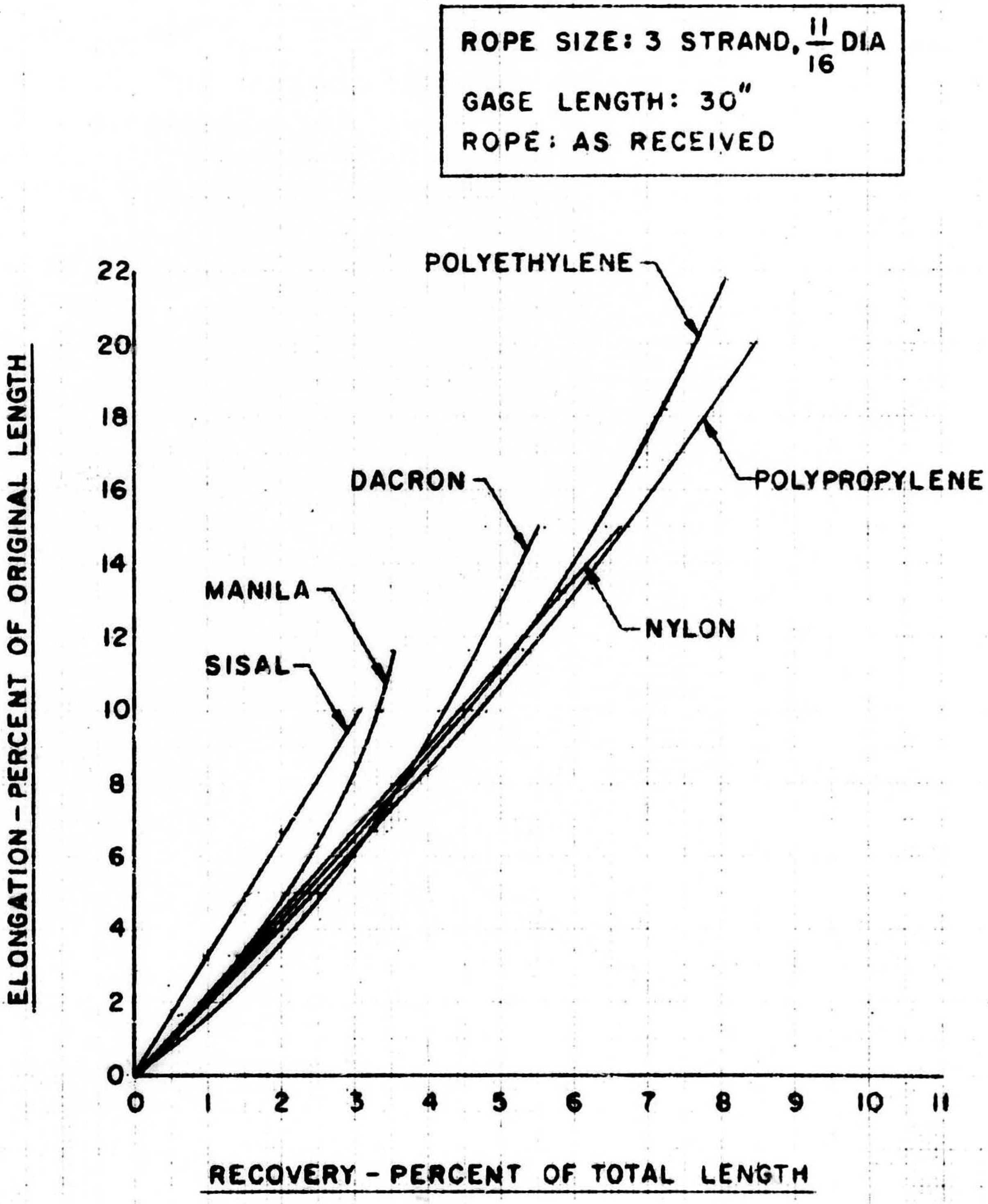


FIGURE NO. 12

RECOVERY VS ELONGATION

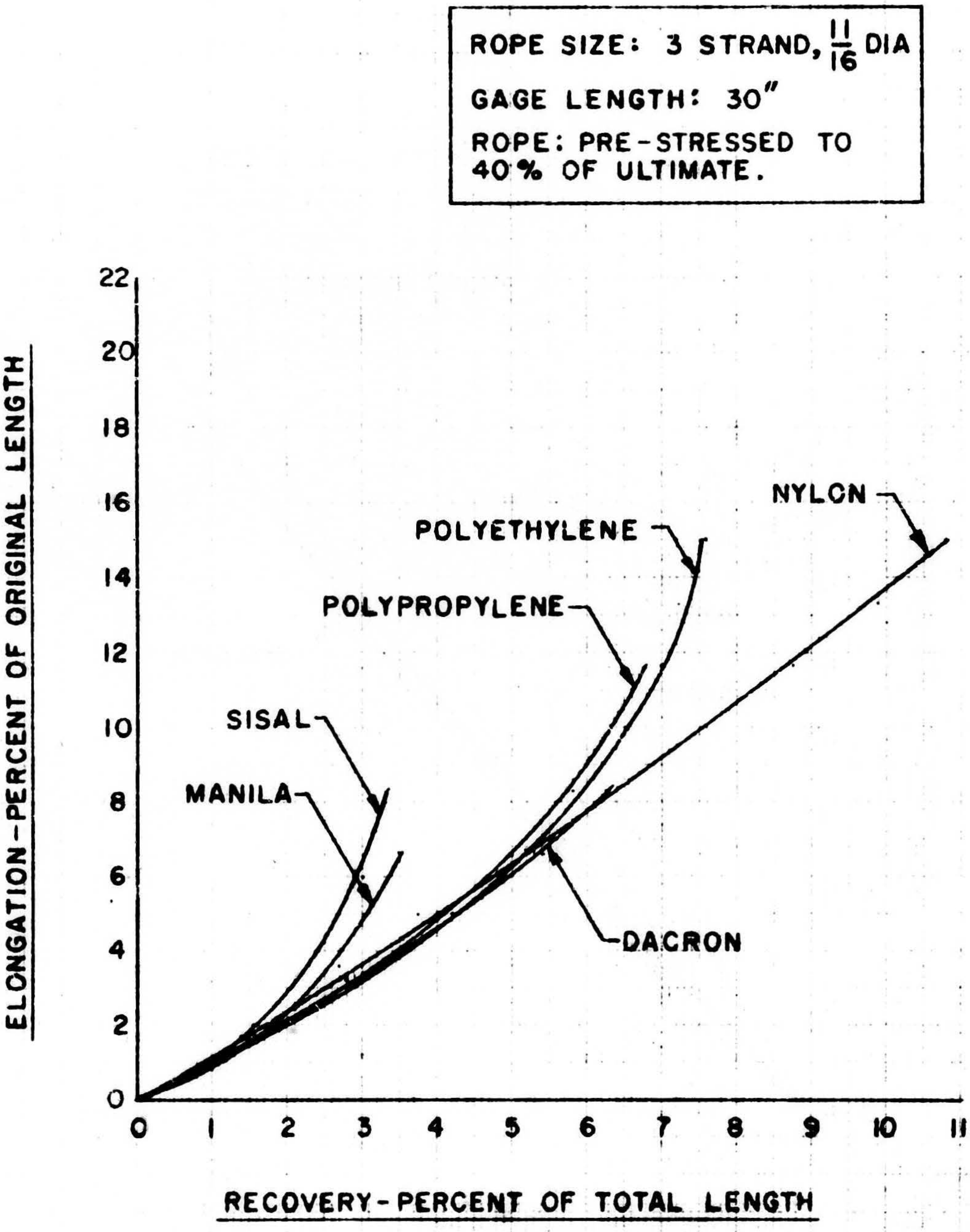


FIGURE NO. 13

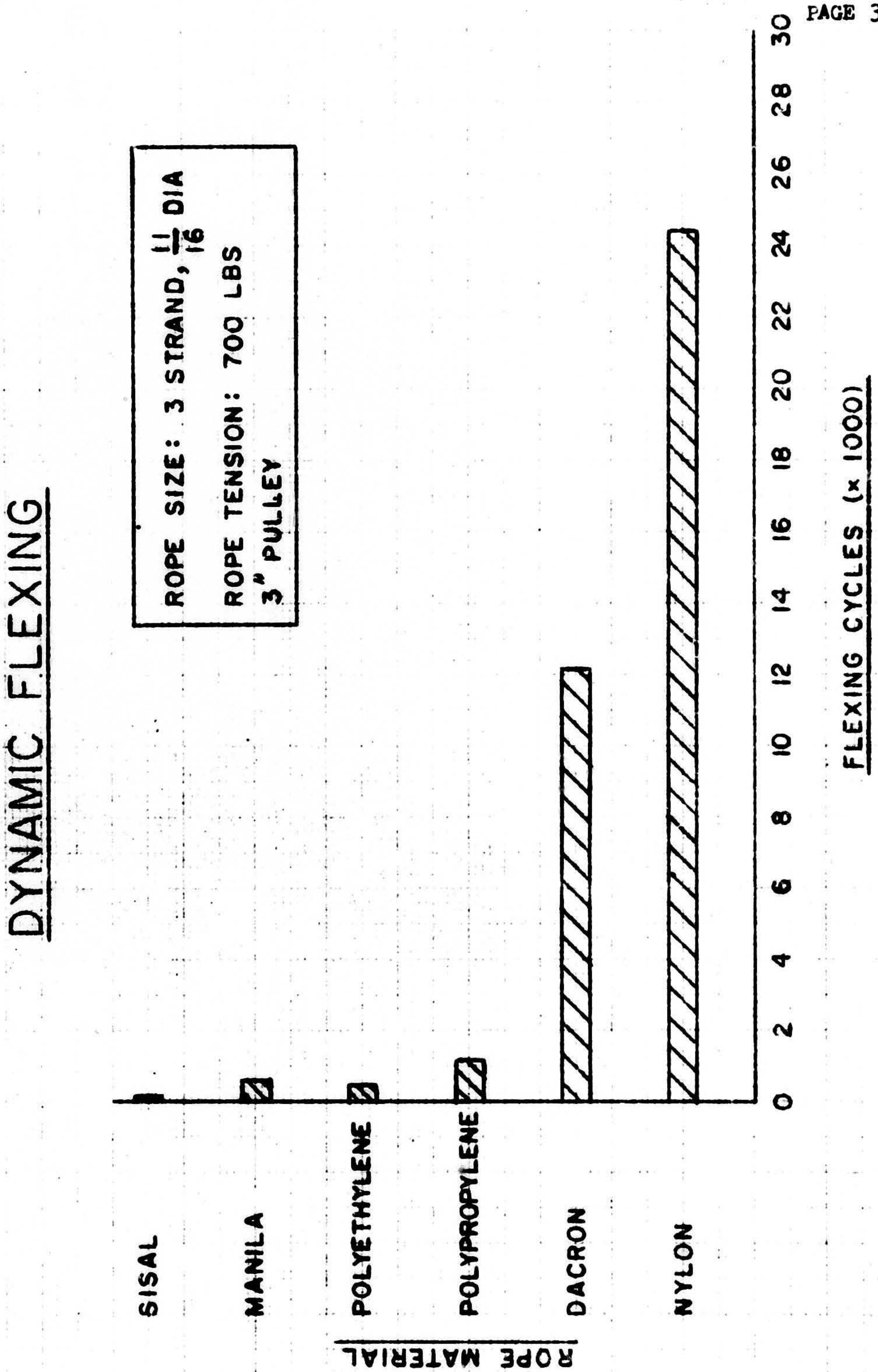

DYNAMIC FLEXING
ROPE SIZE: 3 STRAND, 11/16 DIA
ROPE TENSION: 700 LBS
3" PULLEY
ROPE MATERIAL
SISAL
MANILA
POLYETHYLENE
POLYPROPYLENE
DACRON
NYLON
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
FLEXING CYCLES (× 1000)

FIGURE NO. 14

DYNAMIC FLEXING

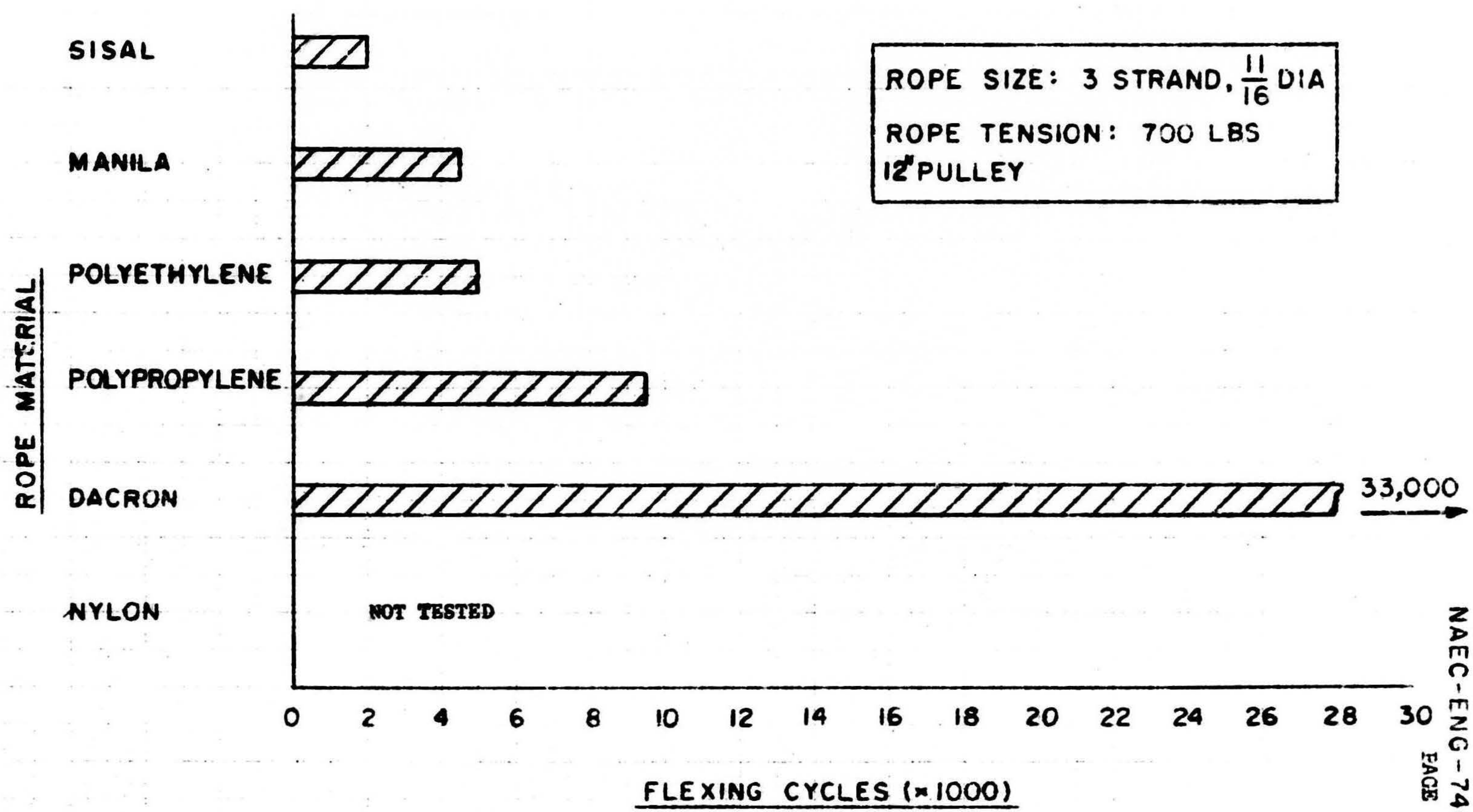


FIGURE NO. 15

ABRASION RESISTANCE

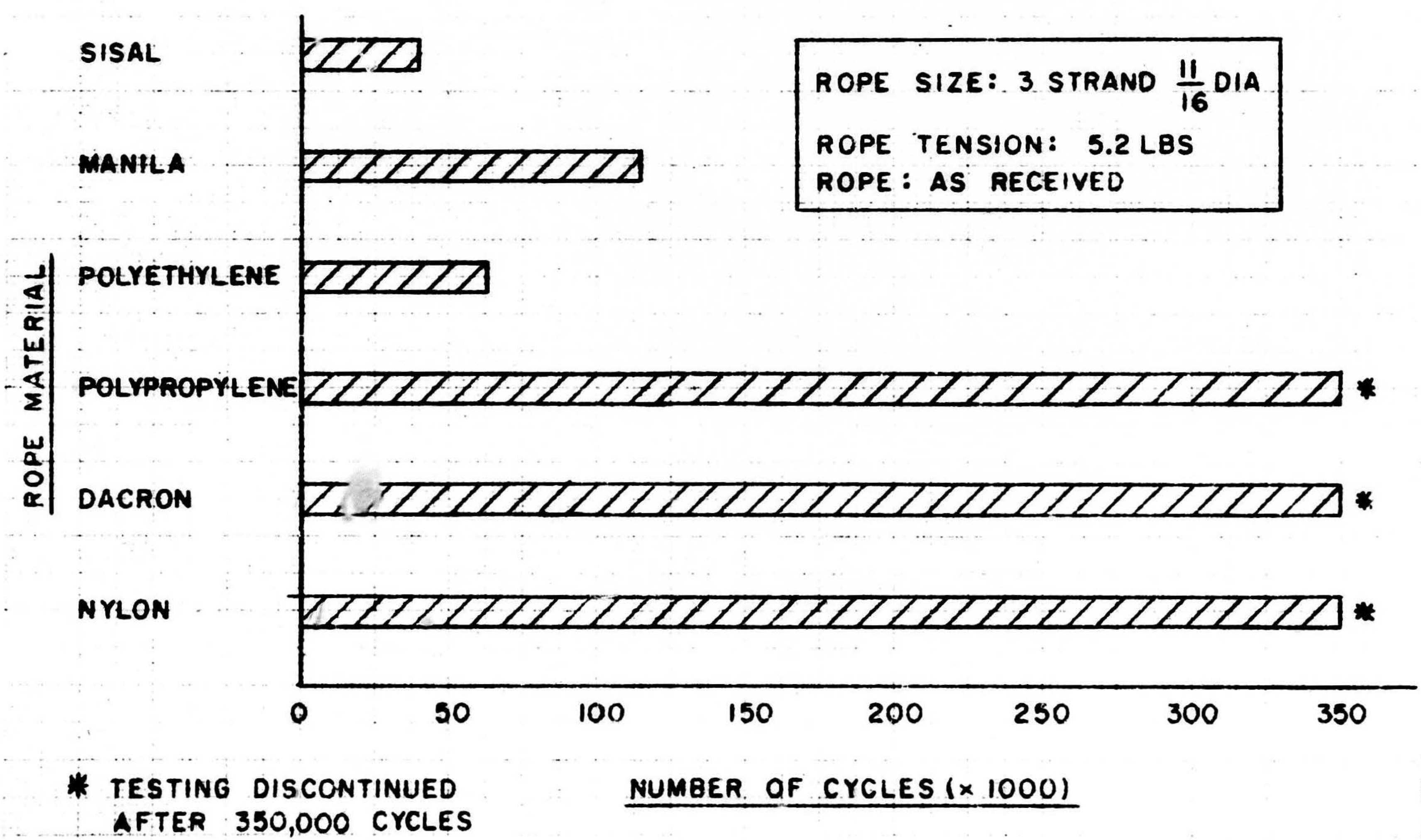


FIGURE NO. 16

ABRASION RESISTANCE

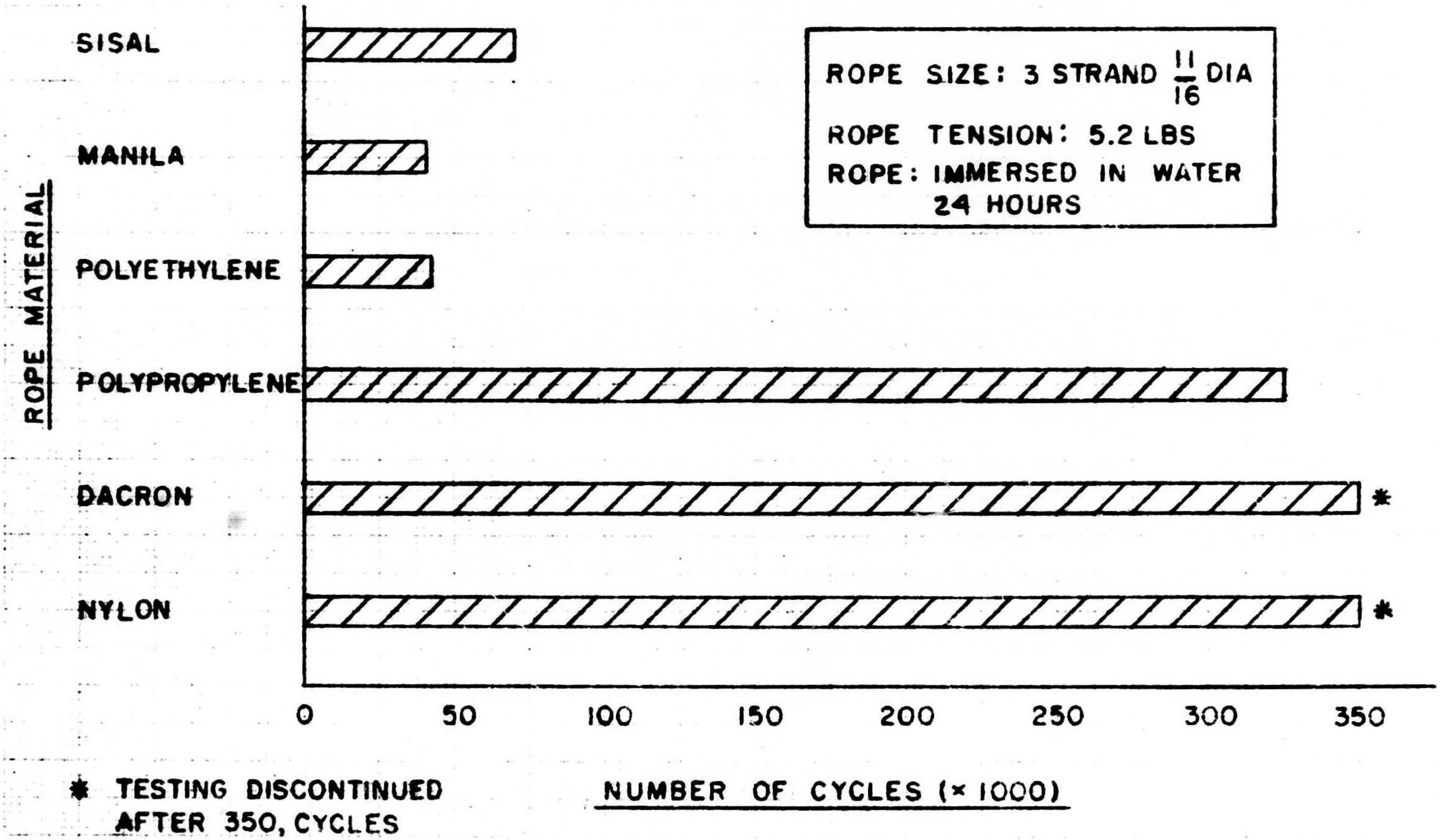


FIGURE NO. 17

TABLE I- PHYSICAL PROPERTIES OF TEST ROPE

PROPERTIES	CORE MATERIAL					
	SISAL	MANILA	P-PROPYLENE	P-ETHYLENE	DACRON	NYLON
ROPE DIA-INCHES	11/16	45/64	11/16	11/16	.671	.687
YARN SIZE	14 ENDS @ 23 T WT-1 END @ 28T	14 ENDS @ 20 1/2 T WT	21600 DENIER	22600 DENIER	1 PLY 18700 DENIER	1 PLY 15120 DENIER
ROPE LAY (TURNS PER FOOT)	6.40	6.15	5.60	5.70	6.80	7.05
LUBE CONTENT %	13.5	13.0	3.32	—	1.3	1.6
WEIGHT/100 FT	17.2	17.3	9.67	10.25	14.5	12.1
YARNS/STRAND	14	15	16	16	22	24

TABLE II - COEFFICIENT OF FRICTION

MATERIAL	STATIC FRICTION		DYNAMIC FRICTION	
	FORCE TO START MOTION F - LBS	COEFFICIENT $\frac{F}{N} = f$	FORCE TO CONTINUE MOTION F - LBS	COEFFICIENT $\frac{F}{N} = f$
SISAL	12.0	0.24	11.5	0.23
MANILA	13.5	0.27	13.0	0.26
POLYPROPYLENE	8.5	0.17	8.0	0.16
POLYETHYLENE	7.5	0.15	7.0	0.14
NYLON	11.5	0.23	11.0	0.22
DACRON	7.75	0.155	7.5	0.15

CORE MATERIAL TO STAINLESS STEEL
NORMAL FORCE ON ROPE N = 50 LBS

TABLE III - EFFECT OF HEAT ON DEFORMATION

MATERIAL	1/2 HOUR EXPOSURE		1 HOUR EXPOSURE	
	DEFLECTION INCHES A	% DEFORMATION $\frac{A}{B} \times 100$	DEFLECTION INCHES A	% DEFORMATION $\frac{A}{B} \times 100$
SISAL	0.015	2.18	0.025	3.63
MANILA	0.010	1.45	0.018	2.62
POLYPROPYLENE	0.012	1.75	0.014	2.04
POLYETHYLENE	0.013	1.90	0.021	3.05
NYLON	0.004	0.58	0.005	0.73
DACRON	0.005	0.73	0.005	0.73

TEST TEMPERATURE - 180° F
CORE DIAMETER B - 0.688 INCHES

APPENDIX A

TEST DATA AND CALCULATIONS

I - TEST DATA

TEST - Resistance to Squeezing, MAT'L - Sisal as Received

Load - Lbs.	Deflection - Inches				
	Room Temp. No. 1	Room Temp. No. 2	120°F No. 1	180°F No. 1	180°F No. 2
100	0	0	0	0	0
1000	.025	.025	.025	.050	.039
2000	.055	.051	.049	.090	.080
3000	.079	.072	.072	.120	.110
4000	.098	.090	.098	.144	.133
5000	.116	.106	.115	.163	.154
6000	.128	.121	.131		
7000	.142	.134	.146		
8000	.152	.145	.160		
9000	.163	.156			
10000		.165			

Defl. Inches	Load				
	Room Temp. No. 1	Room Temp. No. 2	120°F No. 1	180°F No. 1	180°F No. 2
.172	10,000	10,500	8,800	5,140	5,960

TEST - Resistance to Squeezing, MAT'L - Manila as Received

Load - Lbs	Deflection - Inches				
	Room Temp. No. 1	Room Temp. No. 2	120°F No. 1	180°F No. 1	180°F No. 2
100	0	0	0	0	0
1000	.035	.041	.044	.034	.034
2000	.066	.076	.079	.074	.066
3000	.091	.101	.105	.107	.094
4000	.111	.121	.126	.132	.123
5000	.128	.138	.143	.155	.144
6000	.144	.152	.159		.164
7000	.156	.165			
8000	.167				

Defl. Inches	Load				
	Room Temp. No. 1	Room Temp. No. 2	120°F No. 1	180°F No.1	180°F No.2
.172	8,260	7,820	7,000	5,800	6,200

TEST - Resistance to Squeezing, MAT'L - Polypropylene as Received

Load - Lbs.	Deflection - Inches				
	Room Temp. No. 1	Room Temp. No. 2	120°F No. 1	180°F No. 1	180°F No. 2
100	0	0	0	0	0
1000	.043	.046	.062	.050	.070
2000	.092	.097	.104	.106	.107
3000	.121	.128	.131	.141	.142
4000	.141	.150	.151	.167	.166
5000	.158	.167	.167		

Defl. Inches	Load				
	Room Temp. No.1	Room Temp. No. 2	120°F No. 1	180°F No.1	180°F No. 2
.172	5900	5100	5040	4020	4080

TEST - Resistance to Squeezing, MAT'L - Polyethylene as Received

Load - Lbs.	Deflection - Inches Room Temp. No. 1	Room Temp. No. 2	120°F No. 1	180°F No. 1	180°F No. 2
100	0	0	0	0	0
1000	.059	.056	.061	.065	.061
2000	.098	.093	.107	.109	.111
3000	.124	.124	.134	.130	.144
4000	.145	.145	.152	.155	.165
5000	.162	.162			

Defl. Inches	Load Room Temp. No. 1	Room Temp. No. 2	120°F No. 1	180°F No. 1	180°F No. 2
.172	5,440	5,560	5,000	4,680	4,280

TEST - Resistance to Squeezing - MAT'L - Nylon as Received

Load - Lbs.	Deflection - Inches				
	Room Temp. No. 1	Room Temp. No. 2	120°F No. 1	180°F No. 1	180°F No. 2
100	0	0	0	0	0
1000	0.069	0.068	0.075	0.063	0.080
2000	0.108	0.108	0.120	0.111	0.128
3000	0.132	0.133	0.150	0.142	0.157
4000	0.151	0.151	-	0.163	-
5000	0.166	0.167	-	-	-

Load To Defl. Inches	Load				
	Room Temp. No. 1	Room Temp No. 2	120°F No. 1	180°F No. 1	180°F No. 2
.172	5540	5380	3980	4520	3720

(End Point)

TEST - Resistance to Squeezing - MAT'L - Dacron as Received

Load - Lbs.	Deflection - Inches				
	Room Temp. No. 1	Room Temp No. 2	120°F No. 1	180°F No. 1	180°F No. 2
100	0	0	0	0	0
1000	0.075	0.076	0.072	0.076	0.070
2000	0.110	0.111	0.110	0.115	0.110
3000	0.133	0.133	0.133	0.140	0.136
4000	0.150	0.150	0.151	0.158	0.155
5000	0.164	0.163	0.165	-	0.171

Load To Defl. Inches	Load				
	Room Temp. No. 1	Room Temp. No. 2	120°F No. 1	180°F No. 1	180°F No. 2
0.172	5720	5840	5600	4960	5060

(End Point)

TEST - Stretch and Recovery, MAT'L - Sisal as Received
ORIG. LGTH. - 30 Inches

Stretch Inches	Specimen No. 1		Specimen No 2		Specimen No. 3	
	Load Lbs.	Recovery Length Inches	Load Lbs.	Recovery Length Inches	Load Lbs.	Recovery Length Inches
30-1/2	400	30-3/8	400	30-5/16	340	30-7/16
31	750	30-11/16	780	30-11/16	610	30-3/4
31-1/2	1160	31-1/8	1200	30-15/16	1020	31
32	1650	31-1/2	1720	31-1/4	1520	31-3/8
32-1/2	2040	31-5/8	2350	31-7/16	2120	31-5/8
33	2930	32-1/16	3000	31-15/16	2780	32
33-1/2	---		3900	32-5/16	3680	32-5/16

Failure - Specimen No. 1 - Load 3630 lbs., Stretch 33-1/4
Specimen No. 2 - Load 3920 lbs., Stretch 33-1/2
Specimen No. 3 - Load 3750 lbs., Stretch 33-9/16

TEST - Stretch and Recovery, MAT'L - Sisal Pre-stressed to 1400 Lbs.
ORIG. Lgth. - 30 Inches

Stretch Inches	Specimen No. 4		Specimen No. 5	
	Load Lbs.	Recovery Length Inches	Load Lbs.	Recovery Length Inches
30-1/2	950	30-1/8	980	30-1/16
31	1580	30-5/16	1670	30-5/16
31-1/2	2200	30-5/8	2250	30-5/8
32	2850	31	3000	31
32-1/2	3800	31-7/16	4000	31-7/16

Failure - Specimen No. 4 - Load 3820 lbs., Stretch 32-9/16
Specimen No. 5 - Load 4010 lbs., Stretch 32-1/2

TEST - Stretch and Recovery, MAT'L - Manila as Received
ORIG. LGTH. - 30 Inches

Stretch Inches	Specimen No. 1		Specimen No. 2		Specimen No. 3	
	Load Lbs.	Recovery Length Inches	Load Lbs.	Recovery Length Inches	Load Lbs.	Recovery Length Inches
30-1/2	250	30-3/8	290	30-5/16	280	30-3/8
31	530	40-9/16	580	30-5/8	580	30-5/8
31-1/2	930	30-7/8	980	30-13/16	960	30-7/8
32	1460	31-1/4	1560	31-1/8	1540	31-3/16
32-1/2	2160	31-9/16	2300	31-1/2	2280	31-9/16
33	2870	31-7/8	3120	31-15/16	3100	31-15/16
33-1/2	3960	32-1/4	4280	32-3/8	4350	32-3/8

Failure - Specimen No. 1 - Load 5050 lbs., Stretch 33-5/8
Specimen No. 2 - Load 4980 lbs., Stretch 33-5/8
Specimen No. 3 - Load 5210 lbs., Stretch 33-11/16

TEST - Stretch and Recovery; MAT'L - Manila Pre-stressed to 1760 Lbs.
ORIG. LGTH. - 30 Inches

Stretch Inches	Specimen No. 4		Specimen No. 5	
	Load Lbs.	Recovery Length Inches	Load Lbs.	Recovery Length Inches
30-1/2	890	30	920	30
31	1910	30-3/16	1880	30-1/8
31-1/2	2830	30-1/2	2710	30-9/16
32	4150	30-13/16	3890	30-15/16

Failure - Specimen No. 4 - Load 4920 lbs., Stretch 32-1/16
Specimen No. 5 - Load 5190 lbs., Stretch 32-3/8

TEST - Stretch and Recovery, MAT'L - Polyethylene as Received
ORIG. LGTH. - 30 Inches

Stretch Inches	Specimen No. 1		Specimen No. 2		Specimen No. 3	
	Load Lbs.	Recovery Length Inches	Load Lbs.	Recovery Length Inches	Load Lbs.	Recovery Length Inches
30-1/2	230	30-5/16	280	30-1/4	260	30-1/4
31	430	30-1/2	460	30-1/2	480	30-1/2
31-1/2	650	30-3/4	630	30-3/4	720	30-3/4
32	900	31	900	31	960	31
32-1/2	1150	31-1/4	1130	31-1/4	1180	31-1/16
33	1410	31-1/2	1380	31-1/2	1410	31-1/2
33-1/2	1580	31-3/4	1620	31-3/4	1680	31-3/4
34	1840	32	1860	32	1940	32
34-1/2	2120	32-1/4	2140	32-5/16	2210	32-1/4
35	2350	32-1/2	2380	32-1/2	2450	32-7/16
35-1/2	2630	32-7/8	2640	33	2700	32-13/16
36	2860	33-1/4	2880	33-1/4	2930	33-1/4
36-1/2	3080	33-9/16				

Failure - Specimen No. 1 - Load 4310 lbs.

Specimen No. 2 - Load 4250 lbs.

Specimen No. 3 - Load 4160 lbs.

TEST - Stretch and Recovery, MAT'L - Polyethylene Pre-stressed to 2080 Lbs.
ORIG. Lgth. - 30 Inches

Stretch Inches	Specimen No. 1		Specimen No. 2	
	Load Lbs.	Recovery Gauge Inches	Load Lbs.	Recovery Gauge Inches
30-1/2	700	30	660	30-1/8
31	1050	30	1050	30-1/4
31-1/2	1750	30-1/8	1560	30-5/16
32	2200	30-3/16	1920	30-5/16
32-1/2	2540	30-3/4	2160	30-9/16
33	2880	31	2750	30-5/8
33-1/2	3180	31-1/4	2960	31-1/16
34	3590	31-9/16	3320	31-1/2
34-1/2	3900	32	3600	31-3/4
35			3930	32-11/16

Failure - Specimen No. 1 - Load 4640 lbs.
Specimen No. 2 - Load 4500 lbs.

TEST - Stretch and Recovery, MAT'L - Polypropylene as Received
ORIG. LGTH. - 30 inches

Stretch Inches	Specimen No. 1		Specimen No. 2		Specimen No. 3	
	Load Lbs.	Recovery Length Inches	Load Lbs.	Recovery Length Inches	Load Lbs.	Recovery Length Inches
30-1/2	220	30-5/16	210	30-1/4	200	30-5/16
31	390	30-5/8	370	30-1/2	370	30-5/8
31-1/2	640	30-3/4	660	30-3/4	590	30-13/16
32	920	30-7/8	920	30-7/8	890	30-15/16
32-1/2	1240	31-3/16	1240	31-1/8	1170	31-3/16
33	1630	31-3/8	1560	31-5/16	1520	31-7/16
33-1/2	1960	31-5/8	1950	31-3/4	1900	31-11/16
34	2330	31-7/8	2350	31-15/16	2280	32
34-1/2	2780	32-1/8	2820	32-1/4	2680	32-3/16
35	3220	32-3/8	3230	32-7/16	2980	32-1/2
35-1/2	3730	32-5/8	3650	32-13/16	3450	32-13/16
36	4200	32-15/16	4080	33-1/16	3900	33

Failure - Specimen No. 1 - Load 8030 lbs.

Specimen No. 2 - Load 7820 lbs.

Specimen No. 3- Load 7870 lbs.

TEST - Stretch and Recovery, MAT'L - Polypropylene Pre-stressed to 2400 Lbs.
Orig. Lgth. - 30 Inches

Stretch Inches	Specimen No. 1		Specimen No. 2	
	Load Lbs.	Recovery Gauge Inches	Load Lbs.	Recovery Gauge Inches
30-1/2	620	30-1/16	560	30-1/16
31	1120	30-1/8	1050	30-1/8
31-1/2	1640	30-1/4	1630	30-5/16
32	2130	30-5/16	2100	30-3/8
32-1/2	2680	30-4/16	2660	30-5/8
33	3200	30-13/16	3140	30-15/16
33-1/2	3790	31-3/16	3580	31-1/4
34			3890	31-3/8

Failure - Specimen No. 1 - Load 7770 lbs.
Specimen No. 2 - Load 7790 lbs.

TEST - Stretch and Recovery, MAT'L - Nylon Original
ORIG. LGTH. - 30 Inches

Stretch Inches	Specimen No. 1		Specimen No. 2		Specimen No. 3	
	Load Lbs.	Recovery Length Inches	Load Lbs.	Recovery Length Inches	Load Lbs.	Recovery Length Inches
30-1/2	180	30-5/16	190	30-1/4	180	30-5/16
31	280	30-5/8	280	30-1/2	260	30-5/8
31-1/2	400	30-13/16	410	30-11/16	370	30-3/4
32	530	31-1/16	520	30-15/16	480	31-1/8
32-1/2	630	31-5/16	610	31-3/8	590	31-1/4
33	760	31-7/16	750	31-9/16	720	31-1/2
33-1/2	880	31-3/4	880	31-9/16	830	31-11/16
34	990	32-1/16	990	31-15/16	920	32
34-1/2	1120	32-5/16	1140	32-3/16	1070	32-1/4

Failure - Specimen No. 1 - Load 9990 lbs.

Specimen No. 2 - Load 9740 lbs.

Specimen No. 3 - Load 8720 lbs.

TEST - Stretch and Recovery, MAT'L - Nylon Pre-stressed to 3880 Lbs.
ORIG. LGTH. - 30 Inches

Stretch Inches	Specimen No. 1		Specimen No. 2	
	Load Lbs.	Recovery Length Inches	Load Lbs.	Recovery Length Inches
30-1/2	370	30-1/16	360	30-1/16
31	670	30-1/8	610	30-1/8
31-1/2	850	30-1/4	820	30-3/16
32	1170	30-5/16	1130	30-5/16
32-1/2	1460	30-3/8	1400	30-3/8
33	1820	30-1/2	1770	30-1/2
33-1/2	7280	30-9/16	2200	30-9/16
34	2840	30-5/8	2690	30-5/8
34-1/2	3250	30-13/16	3020	30-3/4

Failure - Specimen No. 1 - Load 9920 lbs.
Specimen No. 2 - Load 9240 lbs.

TEST - Stretch and Recovery, MAT'L - Dacron Original
ORIG. LGTH. - 30 Inches

Stretch Inches	Specimen No. 1		Specimen No. 2		Specimen No. 3	
	Load Lbs.	Recovery Length Inches	Load Lbs.	Recovery Length Inches	Load Lbs.	Recovery Length Inches
30-1/2	270	30-1/4	280	30-1/4	200	30-3/8
31	460	30-7/16	470	30-7/16	490	30-7/16
31-1/2	690	30-3/4	730	30-11/16	740	30-11/16
32	950	31	1020	31	1040	31
32-1/2	1290	31-5/16	1360	31-5/16	1410	31-1/4
33	1560	31-5/8	1730	31-5/8	1800	31-5/8
33-1/2	2100	31-15/16	2180	32	2300	32
34	2570	32-1/4	2650	32-5/16	2810	32-5/16
34-1/2	2970	32-9/16	3080	32-9/16	3550	32-5/8

Failure - Specimen No. 1 - Load 9710 lbs.
Specimen No. 2 - Load 9460 lbs.
Specimen No. 3 - Load 9790 lbs.

TEST - Stretch and Recovery, MAT'L - Dacron Pre-stressed to 3800 #
ORIG. LGTH. - 30 Inches

Stretch Inches	Specimen #1		Specimen No. 2	
	Load Lbs.	Recovery Length Inches	Load Lbs.	Recovery Length Inches
30-1/2	580	30-1/16	850	30
31	1180	30-3/16	1500	30
31-1/2	2010	30-5/16	2150	30-1/8
32	2760	30-3/8	2930	30-5/16
32-1/2	3760	30-1/2	3800	30-7/16

Failure - Specimen No. 1 - Load 9020 lbs.
Specimen No. 2 - Load 9090 lbs.

II CALCULATIONS

Tabulation of Data and Calculations Used for Preparation of Stretch and Recovery Curves Shown on Figures 10 thru 13

Gage Length of Rope 30 Inches at 100 Pound Load

Percent Stretch = Column 4

$$\frac{\text{Column 1} - 30}{30} \times 100$$

Percent Recovery =

$$\frac{\text{Column 1} - \text{Column 3}}{\text{Column 1}} \times 100$$

Material: Sisal - As Received P = Load at Failure, 3,766 Pounds					
1 Stretch Inches	2 Avg. Load Lb	3 Avg. Recovery	4 % Stretch	5 % Recovery	6 Load % P
30.5	380	30.375	1.67	.41	10.1
31	713	30.709	3.31	.94	18.9
31.5	1126	31.021	5.00	1.52	30.0
32	1630	31.375	6.66	1.95	43.3
32.5	2170	31.562	8.34	2.88	57.6
33	2903	32.00	10.00	3.04	77.2

Material: Manila - As Received P = Load at Failure, 5,090 Pounds					
① Stretch Inches	② Avg. Load Lb	③ Avg. Recovery	④ % Stretch	⑤ % Recovery	⑥ Load % P
30.5	273	30.354	1.67	.48	5.4
31	563	30.604	3.31	1.28	11.0
31.5	956	30.854	5.00	2.05	18.8
32	1520	31.229	6.66	2.42	30.0
32.5	2246	31.541	8.34	2.96	44.4
33	3030	31.916	10.00	3.30	59.6
33.5	4197	32.333	11.64	3.49	82.4

Material: Dacron - As Received P = Load at Failure, 9,650 Pounds					
① Stretch Inches	② Avg. Load Lb	③ Avg. Recovery	④ % Stretch	⑤ % Recovery	⑥ Load % P
30.5	250	30.291	1.67	.69	2.6
31	473	30.437	3.31	1.82	4.9
31.5	720	30.708	5.00	2.52	7.5
32	1003	31.000	6.66	3.20	10.4
32.5	1353	31.291	8.34	3.71	14.0
33	1700	31.625	10.00	4.17	17.7
33.5	2193	31.979	11.64	4.54	22.7
34	2676	32.291	13.32	5.04	27.6
34.5	3200	32.583	15.00	5.56	33.2

Material: Nylon - As Received P = Load at Failure, 9,450 Pounds					
① Stretch Inches	② Avg. Load Lb	③ Avg. Recovery	④ % Stretch	⑤ % Recovery	⑥ Load % P
30.5	183	30.300	1.67	.66	1.9
31	273	30.600	3.31	1.34	2.9
31.5	393	30.800	5.00	2.22	4.2
32	510	31.000	6.66	3.20	5.4
32.5	610	31.300	8.34	3.70	6.5
33	743	31.500	10.00	4.55	7.9
33.5	863	31.700	11.64	5.38	9.1
34	966	32.000	13.32	5.88	10.2
34.5	1110	32.200	15.00	6.67	11.7

Material: Polyethylene - As Received P = Load at Failure, 4,240 Pounds					
① Stretch Inches	② Avg. Load Lb	③ Avg. Recovery	④ % Stretch	⑤ % Recovery	⑥ Load % P
30.5	256	30.300	1.67	.66	6.1
31	469	30.500	3.31	1.61	10.8
31.5	666	30.750	5.00	2.38	15.7
32	920	31.000	6.66	3.20	21.8
32.5	1150	31.200	8.34	4.00	27.1
33	1400	31.500	10.00	4.55	33.0
33.5	1626	31.750	11.64	5.22	38.3
34	1880	32.000	13.32	5.88	44.4
34.5	2180	32.300	15.00	6.38	51.4
35	2393	32.600	16.65	6.86	56.5
35.5	2680	32.950	18.31	7.20	63.2
36	2890	33.250	20.00	7.65	68.3
36.5	3080	33.562	21.65	8.06	72.7

Material: Polypropylene - As Received P = Load at Failure, 7,900 Pounds					
① Stretch Inches	② Avg. Load Lb	③ Avg. Recovery	④ % Stretch	⑤ % Recovery	⑥ Load % P
30.5	210	30.300	1.67	.66	2.7
31	377	30.600	3.31	1.28	4.8
31.5	630	30.800	5.00	2.22	8.0
32	910	30.900	6.66	3.44	11.5
32.5	1220	31.100	8.34	4.06	15.5
33	1570	31.400	10.00	4.85	19.9
33.5	1930	31.700	11.64	5.38	24.4
34	2320	31.900	13.32	6.18	29.4
34.5	2760	32.200	15.00	6.68	35.0
35	3140	32.437	16.65	7.34	40.0
35.5	3620	32.700	18.31	7.90	46.0
36	4030	33.000	20.00	8.33	51.0

Material: Polyethylene Pre-Stressed to 2080 Pounds P = Load at Failure, 4,570 Pounds					
① Stretch Inches	② Avg. Load Lb	③ Avg. Recovery	④ % Stretch	⑤ % Recovery	⑥ Load % P
30.5	680	30.062	1.67	1.43	14.8
31	1050	30.125	3.31	2.82	22.3
31.5	1655	30.187	5.00	4.17	36.2
32	2060	30.250	6.66	5.46	45.0
32.5	2350	30.625	8.34	5.77	51.3
33	2815	30.875	10.00	6.45	61.5
33.5	3070	31.187	11.65	6.90	66.5
34	3455	31.562	13.32	7.17	75.5
34.5	3750	31.875	15.00	7.62	82.0

Material: Polypropylene Pre-Stressed to 2400 Pounds P = Load at Failure, 7,780 Pounds					
① Stretch Inches	② Avg. Load Lb	③ Avg. Recovery	④ % Stretch	⑤ % Recovery	⑥ Load % P
30.5	590	30.062	1.67	1.43	7.6
31	1085	30.125	3.31	2.82	14.0
31.5	1635	30.312	5.00	3.78	21.0
32	2115	30.375	6.66	5.05	27.2
32.5	2670	30.625	8.34	5.77	34.3
33	3170	30.875	10.00	6.45	40.7
33.5	3685	31.250	11.65	6.74	46.8

Material: Sisal - Pre-stressed to 1400 Pounds
P = Load at Failure, 3,915 Pounds

① Stretch Inches	② Avg. Load Lbs.	③ Avg. Recovery	④ % Stretch	⑤ % Recovery	⑥ Load % P
30.5	965	30.093	1.67	1.34	25.0
31	1625	30.312	3.31	2.22	41.0
31.5	2225	30.625	5.00	2.78	57.0
32	2925	31.000	6.66	3.20	75.0
32.5	3900	31.437	8.34	3.27	99.0

Material: Manila - Pre-stressed to 1760 Pounds
P = Load at Failure, 5,055 Pounds

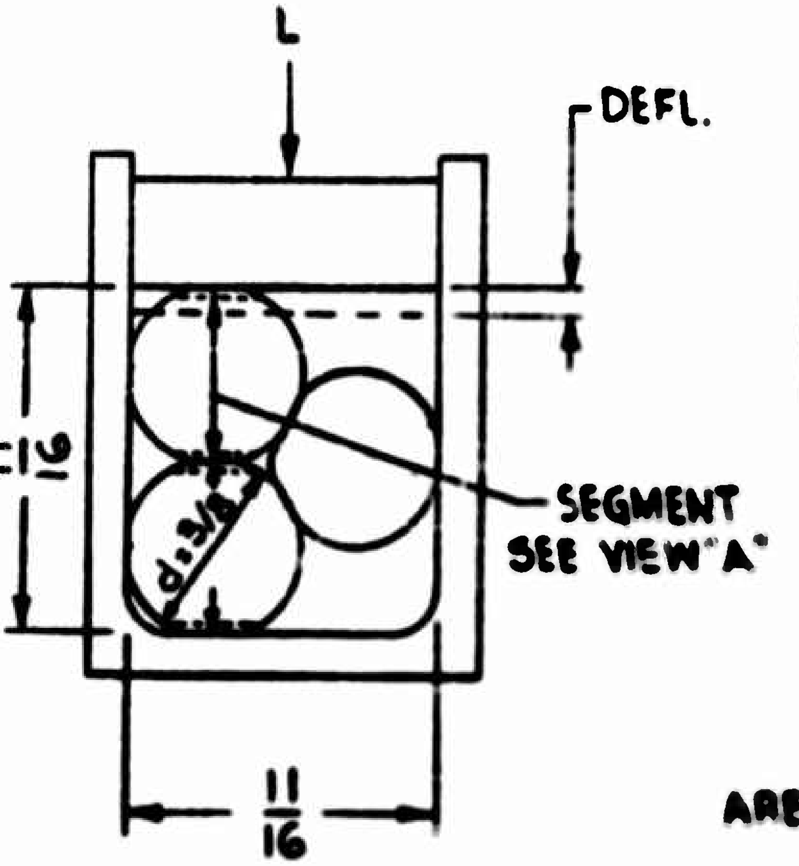
① Stretch Inches	② Avg. Load Lbs.	③ Avg. Recovery	④ % Stretch	⑤ % Recovery	⑥ Load % P
30.5	905	30.000	1.67	1.64	18.0
31	1905	30.156	3.31	2.72	38.0
31.5	2770	30.531	5.00	3.07	55.0
32	4020	30.874	6.66	3.50	3.16

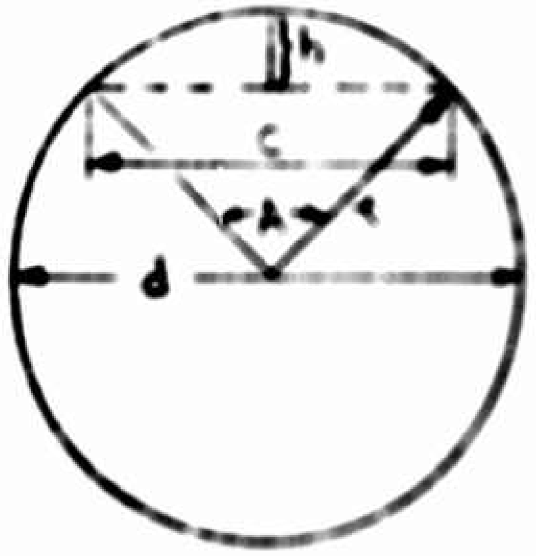
Material: Dacron Pre-Stressed to 3800 Pounds P = Load at Failure, 9,050 Pounds					
① Stretch Inches	② Avg. Load Lb	③ Avg. Recovery	④ % Stretch	⑤ % Recovery	⑥ Load % P
30.5	715	30.031	1.67	1.54	7.9
31	1340	30.094	3.31	2.92	14.8
31.5	2080	30.218	5.00	4.07	23.0
32	2845	30.343	6.66	5.18	31.4
32.5	3780	30.468	8.34	6.25	41.6

Material: Nylon Pre-Stressed to 3880 Pounds P = Load at Failure, 9,580 Pounds					
① Stretch Inches	② Avg. Load Lb	③ Avg. Recovery	④ % Stretch	⑤ % Recovery	⑥ Load % P
30.5	365	30.062	1.67	1.44	3.8
31	615	30.125	3.31	2.82	6.4
31.5	835	30.219	5.00	4.07	8.7
32	1150	30.312	6.66	5.28	12.0
32.5	1430	30.375	8.34	6.54	14.9
33	1795	30.500	10.00	7.58	18.7
33.5	2240	30.562	11.65	8.76	23.4
34	2760	30.625	13.32	9.95	28.8
34.5	3135	30.781	15.00	10.75	32.7

CALCULATION OF BULK MODULUS OF ELASTICITY, K

MATERIAL : POLYPROPYLENE
DEFLECTION : 0.172
TEMPERATURE : 70°F
LOAD L : 5500 LBS





VIEW A

$c = 2\sqrt{h\,(d - h)}$

AREA OF SEGMENT $= 1/2\, r^2$ (RAD A − SIN A)

$$K = \frac{P}{\frac{\Delta V}{V}}, \text{ PSI}$$

VOLUME OF ROPE FOR 1 INCH LENGTH =

$$V = 3 \times \frac{\pi d^2}{4} \times 1 = 3 \times \frac{3.14 \times .375^2}{4} \times 1 = .331 \text{ IN}^3$$

FOR SIMPLICITY ASSUME ALL COMPRESSION IS TAKEN EQUALLY IN THE TOP AND BOTTOM STRANDS AT THE POINTS OF REACTION.

$$h = \frac{.172}{4} = .043, \quad c = 2\sqrt{.043(.375 - .043)} = .24$$

CALCULATION OF BULK (CONT'D)

$$\text{SIN } 1/2\ A = \frac{.12}{.188} = .639\ ,\quad 1/2\ A = 39°40',\ A = 79°20'$$

$$\text{AREA} = 1/2 \times (.188)^2 (1.403 - .983) = 0.0074\ \text{IN}^2$$

$$\Delta V = 4 \times 0.0074 \times 1 = 0.0296\ \text{IN}^3$$

ASSUME 1/3 CIRCUMFERENCE OF TOP STRAND IS IN CONTACT WITH LOAD L.

THEN $P = \dfrac{L}{\frac{\pi d}{3}}$

$$K = \frac{\dfrac{L}{\frac{\pi d}{3}}}{\dfrac{\Delta V}{V}} = \frac{L \times 2.55}{0.0894} = L \times 28.5 = 5500 \times 28.5$$

$K = 157{,}000$ PSI

FOR A DEFLECTION OF .086

$$h = \frac{.086}{4} = 0.0215\ ,\quad C = 2\sqrt{0.0125\,(.375 - 0.0125)} = 0.174$$

$$\text{SIN } 1/2\ A = \frac{0.087}{.188} = 0.463\ ,\quad 1/2\ A = 27.6°,\ A = 55.2°$$

$$\text{AREA} = 1/2\,(.188)^2 (0.9554 - 0.8211) = 0.0177 \times 0.134 = 0.0024\ \text{IN}^2$$

$$\Delta V = 4 \times 0.0024 \times 1 = 0.0096\ \text{IN}^3$$

$$K = \frac{L \times 2.55}{\dfrac{0.0095}{0.331}}$$

$K = L \times 88.0$

CALCULATION OF BULK (CONT'D)

BELOW IS A TABULATION OF "K" VALVES FOR THE CORE MATERIALS AT COMPRESSIONS OF 0.172 AND 0.086:

TABULATION OF "K" AT 70°F (K = LOAD × CONSTANT, C)

MATERIAL	DEFL.	LOAD, LBS	CONSTANT "C"	K, PSI
MANILA	0.172	8,040	28.5	229,000
SISAL		10,250		292,500
POLYETHYLENE		5,500		157,000
POLYPROPYLENE		5,500		157,000
NYLON		5,410		154,000
DACRON	0.172	5,780	28.5	164,000
MANILA	0.086	2,600	88.0	229,000
SISAL		3,550		312,000
POLYETHYLENE		1,900		167,000
POLYPROPYLENE		1,800		158,000
NYLON		1,400		123,000
DACRON	0.086	1,400	88.0	123,000